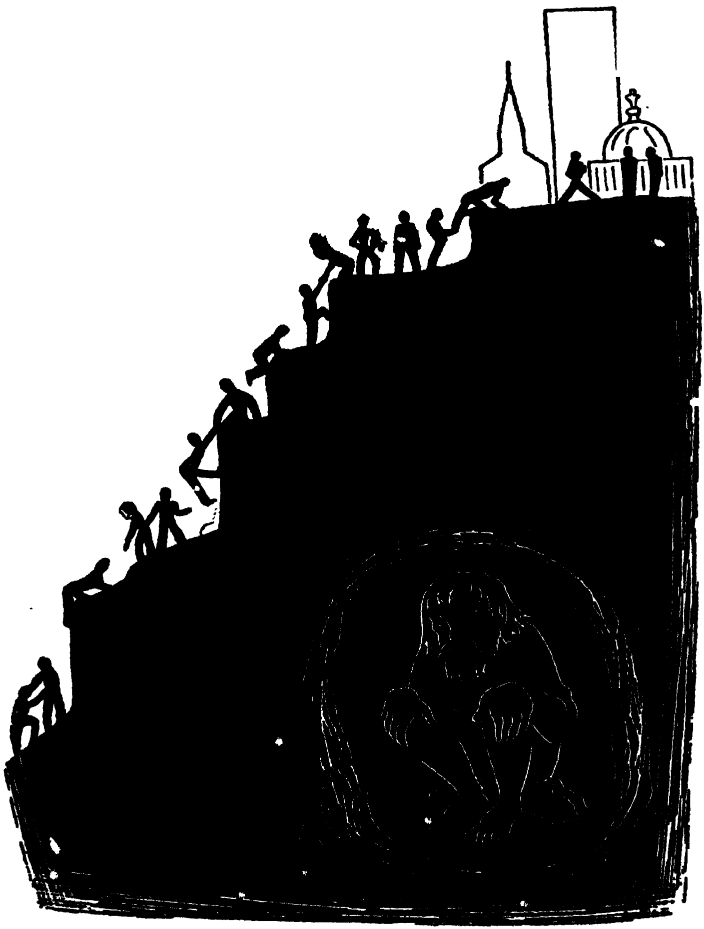
# The Way of Science

## *Its Growth and Method*



*Illustrations by* DWINELL GRANT

# THE WAY OF SCIENCE

*Its Growth and Method*

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To Kent

*"Patient observer" from the very first*

# Contents

# Preface

It is natural to find the study of science expanding in our day. And, along with new patterns in the curriculum, new needs have naturally arisen. If science is to be presented meaningfully to the younger student, he must be given reading which will throw light, in terms he can understand, on several matters of root importance:

1. The methods basic to all science
2. The historical growth of science
3. The relation between natural and social science
4. The connection between sciences and arts

This book tries to fill these needs within the limits of a brief and non-technical presentation. It is de-

signed for use at any stage of the pupil's work in natural or social science, and does not assume any previous training. It can therefore be used as an introduction to science work, or in connection with study at a later stage.

If students enjoy reading this book half as much as I enjoyed writing it, they will never regret the time spent on it. As each chapter was finished, every word was gone over thoroughly by Rose Somerville, as a teacher, and Greg Somerville as a pupil. Their very competent work contributed wonderfully to whatever value the book possesses. Since the former is my wife, and the latter our older son (the other is the "patient observer"), the whole thing is obviously a family affair.

The godfather in the case is Henry Schuman, who is far more than just a publisher. He not only gave his own critical consideration to the work, but enlisted the valuable co-operation of others. To all of these I wish to express my deep appreciation and gratitude.

# The Way of Science

## *Its Growth and Method*

CHAPTER

# 1

# Why We Study Science

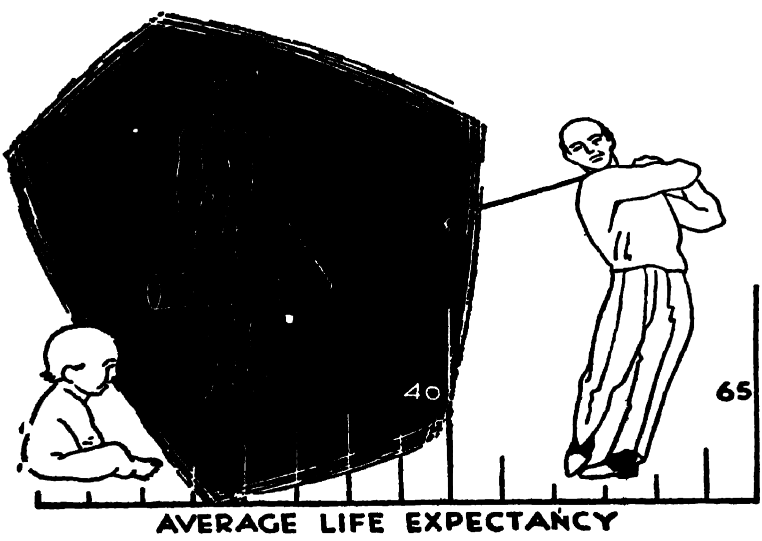
## MODERN SCIENCE AND ALADDIN'S LAMP

Everybody knows that science is a large and important part of our world today. In fact, at almost every moment of our lives, whether we are conscious of it or not, we are relying upon science. It helps us out of many a difficulty that our forefathers never learned to overcome. It brings us many an enjoyment they never dared to hope for. It puts into our hands many a power they never even dreamed of.

As a matter of fact, it is no exaggeration to say that many of us would not be here at all if it were not for science. Take your own classmates for example. Under the conditions of a couple of centuries ago, before medical science was well developed, a considerable proportion of them would not have lived long enough to reach even the age level of your class.

Some would have died at birth, from causes which we now prevent. Others would have died early, from sicknesses like smallpox, which we have practically wiped out through vaccination, or from a number of "children's diseases," such as diphtheria and scarlet fever, which we now control by various forms of treatment or prevention. A number would certainly have died from appendicitis or other such ailments, for many of the surgical operations of the present day were unknown.

Now take, for another example, a gathering of persons of all ages, like those who assemble at graduation day—mothers, fathers, old folks, as well as children. The percentage of "those who wouldn't be there if it



weren't for science" would be even higher. For people today live much longer than was the case a century or two ago. For instance, the average length of life in this country around the 1850's was about forty years. Now the average length of life is more than sixty-five years; and further progress is steadily being made, year by year. A quarter of a century of added life—this is indeed a precious gift. It is there because of the successful efforts of science.

Of course, it is not only medical science, and the fields connected with health, which play an important part in our lives, it is not only when we are ill that we call upon science. Practically all of the time, in health or sickness, awake or asleep, we are making use of its powers.

When we listen to music or speech over the radio, when we see a movie or watch television, when we talk on the telephone or send a telegram, when we read a book by electric light, when we travel by car, plane, rail, or steamboat, when we put a supply of food into a refrigerator or a pile of clothes into a washing machine, whenever we flick a switch, press a button, or read a dial, we are calling upon the sciences and making them work for us. Many of the things we now do in this way, with the help of science, make the story of Aladdin's lamp into an every-day occurrence for each one of us. The "make-believe" of yesterday becomes the reality of today.

In our own country particularly, we see on every side the amazing results of scientific achievement. We use more machines and gadgets—and produce more

machines and gadgets to be used—than any nation in history so far. In other words, ours is the most highly industrialized country the world has yet seen. And the amount of industrial development is one of the most important causes of a nation's power in international affairs. Industry means wealth and weapons—the ability to produce things useful to peace or war.

Now this whole industrial system, as it exists in our land and in others, is the result of science. Factories, plants, power stations, construction projects, communications centers, transportation systems and the like are all examples of applied science. Most of the complex machines, appliances, and gadgets we depend upon in our daily lives are practical applications of modern scientific knowledge.

It is extremely unlikely that anyone could have invented anything like the automobile, electric light, telephone, or radio until the basic principles of sciences like physics and chemistry were established and known. The reason is that these inventions amount to a using of those scientific principles in some particular way that will benefit us. If a person does not know how electricity works, will he have much chance of producing a new electrical appliance? To ask anyone to invent an automobile or radio in a world where physical sciences did not yet exist would be a little like expecting a baby to learn to skate before he has learned to walk. It might be barely possible, but it is hardly probable.

However, once the child has learned to walk, he will probably learn to skate, if he lives in a place where it is

physically possible to do so, and where people like to skate. In the same way, once the laws and principles of sciences like physics and chemistry have been discovered, it is quite likely someone will invent things like the automobile and radio, which apply those principles, which put them to work for us in ways we consider desirable.

Science prevents suffering, cures diseases, lengthens life, wings us through space, transports us on land or water, and under land or water, builds our houses, makes our clothing, preserves our food, purifies our water, increases our enjoyments, deepens our understanding, warms us in winter, cools us in summer, and works for us day and night in a thousand different ways. But that is not the whole picture. There is, unfortunately, a dark and grim side to it as well: Science also threatens to destroy us by means of deadly weapons.

To speak only of the most recent and dramatic of these, it is enough to mention the newer types of atomic bombs, and the "hydrogen bomb," far more powerful than the original atomic bomb. When we reflect that the very first and "simplest" atomic bomb was powerful enough actually to kill more than 150,000 people at one explosion, we realize that the powers of science can cut life short as well as increase it. They can be used either for good or for ill.

These powers are indeed something like the *genie* in Aladdin's magic lamp. Once called forth, they go wherever they are sent, and will do the bidding of whoever is their master and understands them, whether

that bidding is to kill or to cure, to harm or to help. In short, science can be used *for* people or *against* people.

But why should anyone want to use science for wholesale destruction and slaughter? In one sense, the answer is that there is such a thing as war between nations, in the course of which millions of people use deadly weapons to try to kill millions of other people. If each person were asked individually whether he really wanted to kill a lot of other people he had never seen before in his life, the vast majority would undoubtedly answer no.

Why, then, do we find that so many people, on so many occasions, have set out to slaughter one another in international warfare? Why do people find themselves in such a position, doing something they have no real wish to do? It is clear that certain problems and difficulties must have arisen among these people and between these nations which they did not or could not solve in a peaceful way.

### THE PLACE OF SOCIAL SCIENCE

What kind of difficulties and problems are these? They are problems that arise out of living together in the same world. As you know from experience, living together with others in the same house or the same neighborhood, playing with others in the same yard, or working with others in the same classroom can lead to all kinds of disputes and arguments. Sometimes these arguments become fights in which, unfortunately, violence of one kind or another is used.

Now if people who know one another personally, who speak the same language, and who recognize the same government can sometimes get into violent quarrels, it might not seem surprising that nations also can get into such disputes. Indeed, it might be said that nations could more readily fall into disputes, since they do not ordinarily recognize the same government, seldom speak the same language, and sometimes have very different customs and ways of life. Yet they must all share the same world.

The people of different nations trade with one another, sail into one another's harbors, cross one another's lands, visit one another, learn from one another, and enjoy one another's company. In other words, they exchange goods, persons, ideas, songs, information, music and dances, arts and crafts. If they did not do this, life would be dull and primitive indeed.

Problems which arise out of the fact that people live together and have dealings with one another are called *social problems*. Social is a broad term, which includes economic matters, having to do with producing, buying, and selling goods; political matters, having to do with forms of government, constitutions, and laws; domestic matters, having to do with family affairs; educational matters—in fact, everything that concerns group life.

Sometimes problems arise because people or nations cannot manage their economic affairs properly. They may not have enough goods, or they may have too much. They may find it too difficult to make a

living, or they may want to make a living by taking advantage of others, perhaps by robbing them. Sometimes problems arise because people have bad governments, which allow or even compel them to do harmful things they otherwise would not do.

Many difficulties arise out of ignorance. For example, where people know little or nothing about other people or nations, it is easy for fear, suspicion, and prejudice to grow up. And all these may lead to unnecessary disputes.

In other words, many of the causes that make nations quarrel with and war against one another arise from social problems. Many of the causes of trouble or unhappiness *within* a nation spring from the same source. Right here is where science comes into the picture again. One of the most remarkable developments which took place during the last century was the birth of organized *social* science. This is a form of knowledge that is still in the early period of its growth.

Social science, or social studies, includes all fields dealing with social problems: economics, politics, government, history, education, and the like. The idea behind it is simply this: We should try to investigate, observe, and study *social* problems as carefully and systematically as we do *natural* or *physical* problems. If we do, we may little by little build up sciences in these social fields. That is, we may discover all sorts of things about the social problems which will help us to understand and deal with them better. Whenever you know *why* something happens, you are in a much better position to *prevent* or *control* it.

We have, in fact, already accomplished a good deal along this line; and it is our aim to accomplish more and more. If we build up better and better knowledge in our social sciences, we may be able to prevent evil or harmful uses of the discoveries of physical science. We may be able to control various sources of trouble.

Thus, more and better science may well be the answer to the dangers created by certain scientific inventions and discoveries. We may learn through social science to solve many problems which would otherwise lead to large-scale war, or other evils, just as we are now able through physical science to prevent many diseases, which once resulted in countless deaths.

### TO UNDERSTAND THE WORLD BETTER

In all these facts, anyone can see many reasons why we study science: because it so frequently enters into our lives, because it gives us so many benefits, because it can create weapons that threaten us with destruction, because it may be able to remove the causes for using such weapons. These are certainly reasons enough for studying any subject; but in truth, there are other reasons quite as compelling.

Man is not a creature who just takes the world as he finds it, without asking questions. Even a baby is always inquiring: "Why?" and "How?" That's where science often begins. Man wants to *know*. He is not satisfied until he feels he *understands*. If you woke up some morning and found yourself in a strange bed, in a strange house, in a strange land with strange people, you would certainly want to ask many questions. Prob-

ably the first would be: "Where am I? How did I get here? What is this all about?"

You or I would ask these questions not because we were told to or taught to, any more than we breathe because we're told to or taught to. We would ask them because we are normal human beings. A normal human being just does not feel comfortable unless he has some kind of understanding of where he is, how he got there, and what it is all about. Otherwise, he would feel there was something lacking; he would be troubled; he would keep coming back to the questions until he got some kind of answer that satisfied him. The roots of science, the process of question and answer, are in human nature.

In one way, the example we used is not so fanciful as it might seem. In a sense, everyone born into this world finds himself in a strange land with strange people. At least, it is all strange to *him!* Not a bit of it had he ever seen before. So, naturally, the whole business raises a thousand questions in his mind.

The first time a child sees water, he has no idea that it can drown him, or that fire can burn him, or that night always follows day, or that plants grow up from seeds, or that chicks can only come from hen's eggs, or that people are more irritable when they are hungry, or that there are many nations with ways of life different from his own. It is all new.

First of all, he learns that things of this kind do exist and do happen. Some of his knowledge he will undoubtedly acquire the hard way, through bitter experience and many a painful lesson. But the matter does

not end there. It might end there for a dog or a cat, for they, too, learn to accustom themselves to the way things happen and to act accordingly. But it does not end there for a child.

A human being is not satisfied with the mere fact that something *does* happen in a certain way. He wants to know *how* and *why* it happens in that particular way and not some other way, and he keeps trying to find an answer. That is one reason why the human being can claim to be something more than the dog or the cat. *He keeps trying to find an answer.*

For even after we have grown used to the fact that fire burns, the question still remains: Why does fire burn? What happens? What actually takes place? How does fire change a piece of paper or a stick of wood into a little bit of ashes? How is a chick formed from a hen's egg? What actually happens? Why is a person more irritable when he is hungry? What is going on inside him to cause his irritation? Why are there so many nations, with such different ways of life? How did it happen?

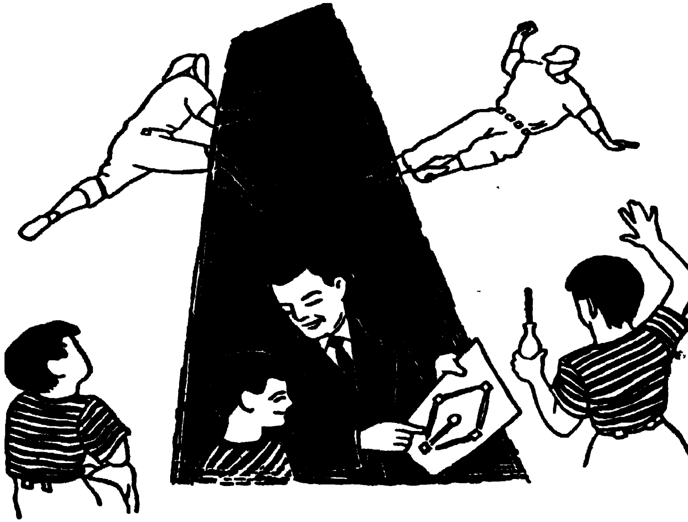
These, and a thousand others like them, are questions we humans ask about the world in which we find ourselves. The best way we have discovered to try to answer them is called science. In other words, science tries to fulfill one of man's strongest needs—to understand. It tries to give him something he always wants —answers to his questions.

## TO ENJOY THE WORLD MORE

There is another fact about yourself that is very important: When you understand something, you enjoy it more. You can see the truth of this clearly in such activities as sports and dances. Suppose, for example, you knew nothing about baseball or football, folk dances or square dances. Even so, you might find a certain amount of interest and enjoyment in watching the games or the dances, in spite of the fact that you did not know "what it was all about." The mere fact that people were running around, kicking or hitting a ball, or keeping time to music in some way, would probably attract and hold your attention for a while.

But how much more interesting and enjoyable these things can be when you know "what it is all about," when you know the rules of the game or the movements of the dance, when you know why a player or dancer is doing what he is doing, when you know what to expect and how to look for the "fine points," when you can "keep score" and judge the abilities of the performers. Then you really enjoy what you are watching. And you can also add to your enjoyment by discussing the event with others, comparing it with past performances or making predictions about future performance.

But, of course, the interest and enjoyment are not only for the spectator. In the great majority of cases, the participants probably get the most enjoyment of all. It is clear that this kind of enjoyment is quite im-



possible without knowledge. Thus, having the fun depends on knowing the game, and knowing the game is part of the fun.

This truth applies not only to pastimes like athletics or dancing. It applies to all of life, to all that we come across in the world. For example, practically everyone likes to see green things growing up in springtime, or to hear the different notes of birds as he walks through the woods, or to look at the sky filled with thousands and thousands of stars on some clear night.

But doesn't it add to our enjoyment when we can recognize and name the different plants and flowers, when we can make predictions about the next stage of their growth and see those predictions come true, when we can identify the various birds, and tell the difference between a note of alarm and a note of joy,

between an aggressive and a friendly call, when we know why certain stars are brighter than others, or what the "milky way" really is, or why there seem to be "falling stars"? Such scientific knowledge brings us closer to the things we enjoy. It deepens and increases our very enjoyment.

There is another side to this: Sometimes we fail to take an interest in and enjoy things just because we don't know enough about them. It may be hard to take much pleasure in something we know very little about. On the other hand, the more we know about something, the more we are able to make of it, the more interesting questions we can raise about it. Knowledge often rouses interest, and interest often leads to more knowledge, which leads to more interest, and so on.

After all, what *is* knowledge? It is the truth about things, which must be discovered. Discovery is adventure. To find out something that was hidden is fun. The human being *enjoys* the process of proving something, of showing that a certain thing is so, or that a certain explanation is right. Just as we find children asking all sorts of questions without being told to, about things which interest them, so we also find them taking enjoyment out of proving and explaining things to one another, long before they go to school.

Why do children who have never even been to school take pleasure in explaining and proving? It is because these things are triumphs, victories, achievements. The unknown, or someone else's lack of knowledge, is a sort of challenge to us. When we accept the

challenge and can show we have discovered the right answer, it is like winning a game. Thus, knowing something, even if it is very simple, and knowing that we know it, is pleasing to us. While science is not simple, it is in some ways like a fascinating game.

### EVERYONE CAN USE THE METHOD OF SCIENCE

Insofar as science is a game, it is one that anybody can learn to play, because the whole basis of science—observing, thinking, explaining, proving—is part of our normal behavior, and an enjoyable part, long before we are able to define the word itself. Science is not a mysterious affair, and the key to it does not belong only to some privileged few. While it is true that people are not all *equally* good at science, or at anything else, everyone can use the method of science to some extent. Everyone can learn to use it better, and thus gain greater benefits, greater understanding, greater enjoyment.

We say everyone can learn to use the method of science *better*, because the fact is that everyone already uses it to some extent, whether he knows it or not. Once I overheard two children seated on the swings side by side in a park playground. They were about five years old. Their conversation went something like this:

"Why is your dog trying to eat that paper?"

"He's not trying to eat the paper."

"He is so. He's licking it and chewing it."

"Then there must be something good *on* the paper."

"I don't see anything *on* the paper. It's just paper."

"There *must* be something on it that's good to eat."

"I don't see anything on it. Maybe your dog just likes paper."

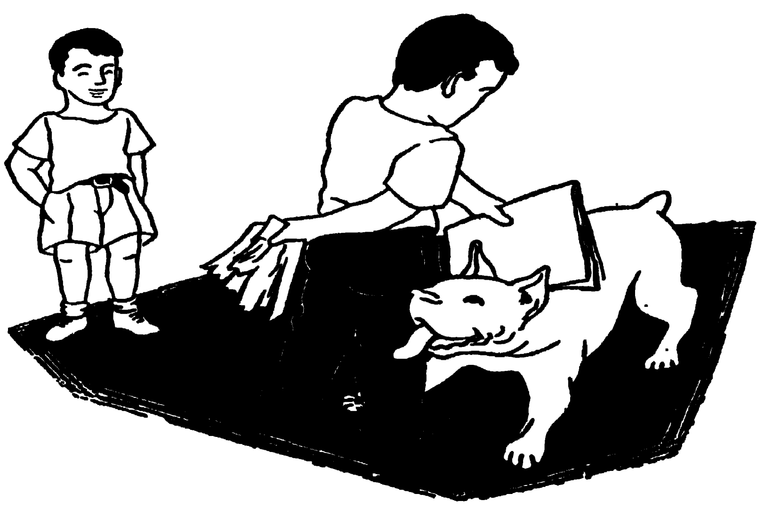
"*He* doesn't like paper. Cricket never eats paper, except when there's something on it."

"I don't believe it. Show me what's on it."

They both got off their swings. After a little difficulty, Cricket's owner took the paper away from the dog. Both children looked it over carefully and smelled it.

"See. I told you. There's nothing to eat on it."

"There must be something on it, but we can't see it. Cricket wouldn't eat *paper*."



"How do you know? He might *like* paper."

"Oh, no. You can give him paper. Go ahead. He won't eat it. He won't even lick it, unless there's something on it. There's a newspaper on that bench. Give it to him."

The other child was afraid to do this, so Cricket's owner stuck the newspaper under the dog's nose. Cricket sniffed it once, and took no further interest in it. But he kept trying to get at the paper that had been taken away from him.

"See? I told you. He wants the first paper 'cause there's something on it."

And the other child, quite reasonably, repeated: "Must be something on it."

Without knowing it, these children were using the basic elements of the scientific method. From their observations they formulated a problem. They discussed possible solutions of it. Then one of them devised an experiment that seemed to prove his solution correct. Of course, it was not complete proof, but it was certainly a beginning.

As a matter of fact, the child's approach in this case was not so very different from that taken by the great French scientist of the nineteenth century, Louis Pasteur, who showed why milk or any other such food goes bad when left exposed. Pasteur's explanation was that tiny organisms (bacteria or microbes), so small we can see them only with a microscope, are floating through the air on various dust particles. These tiny living things drop into the milk, upon which they feed and multiply.

The child had the idea of proving his point by showing that when paper had not been in contact with food, his dog did not try to eat the paper. Pasteur proved his by showing that when he sealed off the milk from contact with the air (after first heating it, so as to kill any organisms already in it), it did not go bad; no microbes could be found in it.

This discovery, by the way, not only led directly to the "pasteurization" processes we use today, but helped to establish the germ theory of disease. "Germs" are forms of bacteria or microbes, and many diseases occur because they get into the human body, where they feed and multiply.

We are all scientists to some extent, for we all use observations and make experiments to try to solve our problems; and we all find it interesting to do so. If we gain a better grasp of science we shall certainly be able to solve our problems more efficiently, understand the world better, and enjoy it more.

CHAPTER

# 2

# How Science Was Born And Began To Grow

### WHY IT HAPPENED TO MAN

How did it happen that no creature except man ever built up sciences? Why couldn't lions or tigers, elephants or monkeys do the same? The answer to this question depends on another. What do you need in order to create such a form of knowledge as science? If you think it over, you may be able to answer this question yourself. It is clear you need a number of things. Just to say "a brain" would be too simple.

For example, wouldn't it be pretty difficult to have sciences unless you already had language? You must be able to name things, keep records of them, write about them and discuss them with others, in order to build up extensive knowledge. For that you need some system of signs that stand for things.

Our language is a system of spoken words that stand for things, and also a system of written symbols that stand for the same things. Everything we *speak* by means of the vocal sounds we can also *write* by means of the visual signs.

We grow so accustomed to using language, spoken and written, that we take it for granted. We are apt to forget that it is an invention, that it had to be created. It is part of the foundation on which science rests.

The first great idea in the invention of language, then, was to have a spoken sound or written symbol stand for a thing, like *tree*, or for a quality, like *large* or *small*. (Sometimes even a gesture symbol would do, as in the case of the "sign language" of certain American Indians.) Then, even in the absence of that thing or quality, it could still be referred to, discussed, explained, communicated to others. Once people got that idea, it was bound to grow, for, by making new symbols, more and more things and qualities could be named, distinguished from others, and thus dealt with better.

The next great idea of language, as we just said, was that one system of symbols, such as spoken sounds, could be translated into another system of symbols, such as written characters. At first, the written characters were pictures, each standing for a complete word. This meant learning a multitude of different characters. Later, alphabets were invented, simplifying the process of reading and writing.

Of course, man could not have invented spoken or written words without certain natural possessions. First of all, he had to have physical senses, particularly sight, hearing, and touch. Without senses, he would not be aware of the world at all; in fact, he would not be alive—at least, not for long. Under ordinary circumstances, to stay alive we must be able to take in food, react to our surroundings, avoid dangers, and the like. To do these things, we rely on the senses.

In the case of spoken language, a good vocal apparatus, capable of making a great variety of sounds, is, of course, extremely useful. For written language, a hand with fingers capable of holding some small implement, and manipulating it with care and exactness, so as to form recognizable characters, is similarly useful. Without such natural possessions, it probably would have been impossible for man to learn to talk and write.

Connected with the physical senses, and with the working of hands and voice, man has the great advantage of a complex brain mechanism. This living instrument allows him to direct and control his movements, to make various muscles and organs of his body do what he wants them to do. It allows him to remember and to think.

If man had never possessed the ability to control his own movements, to handle and manipulate objects around him, it is hard to see how he could have developed much ability to think and reason. Reasoning, if it is to be done at all, has to be about some particular thing. In order to do it, we must be able to focus on

the thing in some way, go to it, examine it, follow it up, and go back to it when we want to think about it again.

If we could not do that sort of thing, it would be impossible for us to develop our reasoning ability. And if we could not develop reasoning ability, it would certainly be impossible for us to build up sciences.

However, does all this explain why lions, tigers, elephants, and monkeys never worked out sciences? Someone might well point to the fact that these animals have very good physical senses, even keener than man's in many ways. They also have a powerful vocal apparatus. And we must not forget that animals of this kind have a brain structure, too. What, then, is the answer?

It is a matter of degree, but that degree is very important. Animals like lions and tigers do have certain sense organs superior to man's, such as that of smell. But this advantage does not make up for the fact that their brain structure is far less complex, and is therefore capable of fewer operations.

Also, lions and tigers have another great disadvantage. Although they have enormous physical strength, they have no bodily members, which, like the fingers, can manipulate things carefully, create and use tools, build things. Until you can perform operations of that kind, you cannot develop much knowledge. For knowledge means finding out how things work, and you cannot find out how things work unless you are able to work *on* them and *with* them, carefully and exactly.

Some lions, as we know, can be taught to perform difficult feats, like jumping through a burning hoop. But even the cleverest lion cannot be taught how to construct and use a microscope. And he will gobble down poisoned meat that can kill him as happily as he does good meat that nourishes him. Some humans are sometimes like that, too. But the difference is that there are other *humans* who do know the facts, and can teach them to those less informed. Unfortunately for lions, there are no such other lions.

Monkeys are much better off as regards hands and fingers, and that is certainly one of the reasons why monkeys are far cleverer than lions or tigers. Monkeys can be taught to use implements that require careful manipulation, such as a knife or fork; and they can learn to operate a fairly complex piece of mechanism, such as a bicycle. It is not at all surprising that creatures who can do things of that kind are closer to man, in the scale of evolution, than lions, tigers or elephants.

However, we are not trying, in this book, to give anything like a complete story of the development of human intelligence. We are only pointing out some of the main things man had to have before he could build up sciences: physical senses, complex brain mechanism, written language, a hand and finger structure capable of making and using tools. Because he possessed and developed a combination of things like these, man, rather than some other creature, became the creator of science.

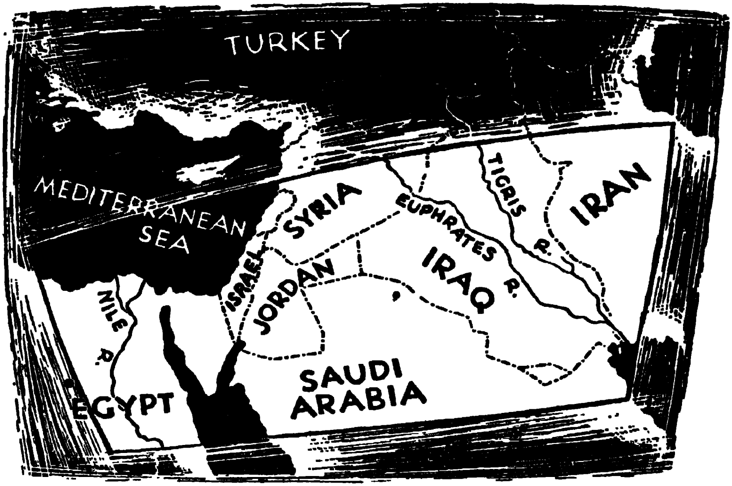
## BEGINNINGS IN THE EAST

If we consider how science began among men, and how it gradually grew up, the history of it in one sense makes it seem very old, and in another sense, very young. It depends upon what we compare it with. According to a good deal of evidence found so far, writing was probably invented about 6,000 years ago in Egypt. And, as we just saw in our discussion, it is impossible to have any real development of scientific knowledge until we have written language.

If we considered science as much as 6,000 years old, that would be a very long time compared to the life span of a person, but it would be a very short period compared to the life span of a planet like our earth. The evidence we now have does not allow us to speak with great exactness, but certain scientists estimate that our earth is now more than a billion years old. In terms of such a time span, 6,000 years ago seems very recent!

Looking ahead into man's future, we might put it this way: If it took man but 6,000 years to progress from the first crude writing to the harnessing of atomic energy, think what he might be able to accomplish in the next 6,000 years of progress! It is almost impossible for us to imagine. How difficult it would have been for the ancient Egyptian, just beginning to grasp the idea of a written language, to look ahead to electric lights, radios, jet aircraft, or atomic energy.

The earliest beginnings of systematic knowledge seem to have occurred in regions which we call today



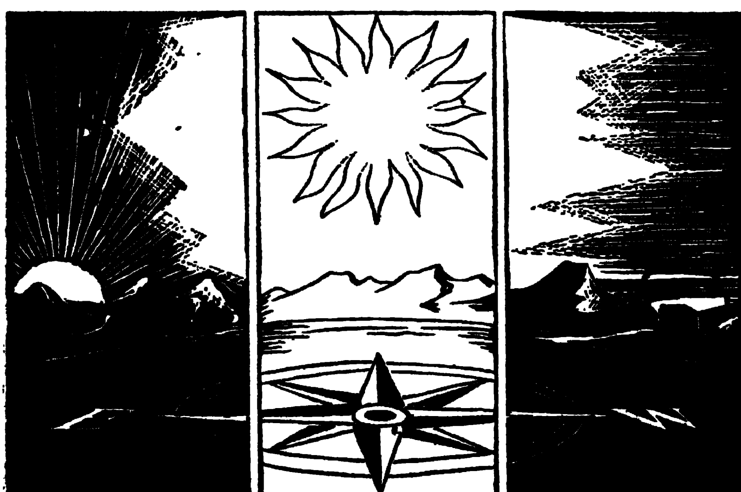

the Near East or Middle East—in Egypt and lands near it, such as ancient Babylonia (a part of the country now called Iraq). In the period between 4000 B.C. (that is, about 6,000 years ago) and 600 B.C. (about 2,500 years ago) the most important successes in the first efforts to build up knowledge were attained in mathematics and astronomy.

Why did the beginnings take place in these subjects? While we cannot yet answer such a question completely, we know many things that certainly throw light upon it. As civilization grew up, some of the earliest pursuits on which people depended were agriculture, the use of animals, and trading. There is a saying, "Necessity is the mother of invention," and it is easy to see the great need for mathematics, especially arithmetic and simple geometry, in order to measure plots of land, build large houses, count stock, and

exchange goods. As early as around 3500 B.C. the Egyptians were using a decimal system of numbers. By 1700 B.C. the foundations of geometry were definitely established.

It is also important that man is a traveling creature, from both necessity and choice. Either in pursuit of food and animals, or out of curiosity, or to engage in trade, people moved about a good deal, over land and water, by day and night. To do that, they needed to know how to tell directions and how to recognize landmarks which everyone could see.

The best "landmarks," which everyone can see, are in the sky. (They are really skymarks.) It is from the rising and setting of the sun in the daytime, and of the stars and moon at night that man was able to establish directions, and guide himself on his travels. These



wonderful lights in the sky move, but they move in regular paths and cycles.

For example, everyone can see that the sun always rises at one side of the horizon, always travels in a regular arc across the sky, and always disappears below the horizon on the other side. Here were direction points that all could agree on: East is where the sun rises, west is where it sets.

Here, also, was the possibility of the same measure of time for everyone: Let a full day and night be considered as all the time between one rising of the sun and its next rising. This unit of time could then be divided into smaller units, such as hours or minutes, and multiplied into larger units, such as weeks and months. The idea of a "day" divided into a definite number of "hours" originated among the Babylonians thousands of years ago. As early as 4000 B.C. Egyptians had established a calendar "year" of 365 days.

When people observe a few things about numbers, measurements, stars and sun that are very helpful to them in their activities, they naturally observe and investigate these things further, just as people who find precious metal near the surface are inclined to dig deeper in the same place. Thus Egyptians, Babylonians, and others worked out a number of simple mathematical principles, and kept good records of many astronomical and other observations. Hence, they were able to survey land, carry on trade and commerce, and even predict eclipses, especially of the moon.

At the same time that these earliest beginnings of

what we now call mathematics and physical science were taking place, people were also, of necessity, attempting to build up social knowledge. They had to try to solve their problems of living together. They set up various forms of government, laws, family systems, economic practices, and the like. For example, one of the oldest known codes of laws is that of Hammurabi (Hahm-oo-rah′-be), a king of Babylon who lived around 2,000 B.C.

These ancient nations did not get very far in the discovery of principles of social science. Yet we can see clearly how the birth of any science at all was made possible and greatly stimulated by the fact that people lived together in communities rather than in isolation.

If human beings had no contact with one another, they would have little need to invent language. If they did not want to build communities where they could live together, they would not need to know much about tools, and such processes as counting, measuring, weighing. If they did not wish to visit one another's countries, or to trade, they would have little need to make charts, build boats, tell directions, and guide travel. In other words, many of the causes for the birth of science would have been lacking.

Man owes a good deal to the fact that he is a group or social animal, not just a "lone wolf." Were he by nature a solitary creature, he would, in all probability, still be without language or science; he would be uncivilized and ignorant—little more than a wild beast.

THE CONTRIBUTION OF ANCIENT GREECE

When we speak of the "ancient world," we usually mean the period of early civilization from around 4,000 years or so before the birth of Christ up to a few centuries after Christ's death. During this period many flourishing cultures were built up by nations in and around the regions we today call the Near East and Middle East. Among them were the Sumerians, Assyrians, and Persians, as well as the Egyptians and Babylonians. Still farther east and south, very important civilizations were created by peoples in different parts of India, China, and Africa. In Europe, the Greeks and Romans were outstanding during this period.

In fact, the greatest contribution of the ancient world to the development of science was made by the Greeks during the period from about 600 B.C. to about 200 B.C. They were such bold and brilliant pioneers in practically all fields of knowledge (as well as in all the arts) that some writers are inclined to say science really originated in Greece. However, we feel that such a statement does an injustice to many earlier peoples who laid the foundations on which the ancient Greeks built so splendidly.

At that time there was no such thing as one country called Greece. There were a number of "city states," each quite small but each governing itself, on the territory we now call Greece, and also on lands farther west and east (Italy and the west coast of present-day

Turkey). In some ways, Greek civilization became a sort of bridge between the culture of peoples farther east, which the Greeks inherited, and the newly developing culture of the west, which they did much to form.

The Greeks, more than any other ancient people of whom we have evidence, seem to have gotten hold of the idea of *applying reason* to practically everything, to all questions and problems concerning life and the world. We take this attitude more or less for granted today, but we should not forget that a good deal of it came to us because of the successful pioneering efforts of the early Greeks.

One reason why it was difficult for people of the ancient world to build up exact knowledge was that magic and superstition played such a large part in their lives. They came only gradually to realize that things are produced by definite, natural causes, each following a regular pattern, and that these causes can be found out by careful observation and logical thinking. Even after such causes were proved for certain things, people were still not convinced that causes could be found working in *all* things.

Another way of stating the same fact is this: People came only gradually to realize that there are laws of nature. That is, when plants grow, or persons get sick, or things fall to the ground, or anything else happens, the processes involved follow definite laws, rules which nature never violates. Things don't happen by magic, and they don't happen just any old way, though it may sometimes seem so.

Many Greek thinkers kept two basic principles in mind and applied them:

1. A thing, whatever it may be—a strange animal, a rainbow, the sun, a thought, a feeling—does not come from nothing. *You cannot get something from nothing.* The "something" always comes from something else. (This principle later became known as the Law of Conservation of Energy or Matter: Energy or matter cannot be made *out of* or *into* nothing.) For example, when we burn a piece of paper we do not destroy the basic content of which it is made—its atoms and energies. This content simply takes a new form—mainly the form of gases.

2. The same cause, under the same conditions, always produces the same effect. That is, if water freezes or fire burns or poison kills under such and such conditions today, it will do the same tomorrow, if the conditions are the same. (This principle is sometimes called the Law of Causation, or the Uniformity of Nature.)

When you think about it, you can see that both these principles were quite necessary to the growth of science. Unless they were accepted, there would hardly be any place for logic, reason, or science at all.

In one sense, what these principles mean is that the things and events of the world are *understandable*. For it is easy to see that if plants, persons, rainbows, diseases, and the other things we meet with really happened out of nothing, everything would be a mystery. We could never account for anything. We could never understand anything.

Likewise, if the same cause under the very same conditions had one effect this time, and an opposite effect next time, everything would be a jumble. We would never know what to expect, even of the simplest things. If we never knew whether two and two were going to make four or ten, or whether fire was going to warm or freeze us, the ability to think logically would be of little use. If the world were really like that, we could hardly expect reasoning power to develop, any more than we could expect musical ability to develop in a world where no one could count on being able to sound the same note twice in the same way.

The leading Greek thinkers insisted that the world is neither a mystery nor a jumble. They were convinced that all things happened in ways that could be understood by the mind of man. They applied that attitude to practically all branches of physical and social knowledge. In doing so, they cleared the ground and took the first systematic steps in many fields of science.

For example, Democritus (Dem-ah′-krit-us) and Leucippus (Lew-kipp′-us) arrived at the conclusion that everything was made up of tiny particles which they called atoms (a Greek word) so small that they were invisible. Of course, these men did not realize that the atom is as complex as we today know it is, but they had the fundamental idea, and made a beginning. That beginning is the basis of sciences like physics and chemistry. Anyone who learns about such sciences will realize the great importance of knowledge about atoms.

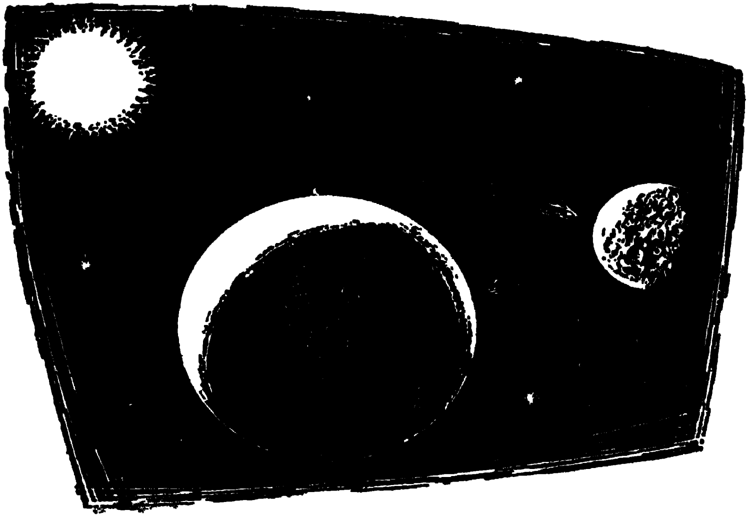
A number of Greeks discovered basic principles of mathematics. The most noted was Euclid, (Yook′-lid) who worked out a whole system of geometry, which we still use and teach today.

Several Greek astronomers suggested that the earth is not flat, but spherical. This, of course, is the correct idea, though it does not seem so from ordinary observation. It is said that Pythagoras (Pith-ag′-or-as) or his followers reasoned that the earth must be a sphere from the shape of its shadow, which can be seen against the moon when there is an eclipse of that body.

For these Greeks also had the right idea about eclipses—that is, that an eclipse of the moon, for example, takes place because the earth for a short while comes directly between the sun and the moon, as these bodies move in the sky. Hence the earth's shadow falls on the moon, gradually blotting out the moon's light as the shadow advances.

This reasoning indicates another fact: Some of the Greeks also had come to the correct conclusion that the moon's "light" is not its own, but is only reflected sunlight. In other words, even though we cannot see the sun at night, it is still shining as brightly as ever on the other side of our earth. Its rays are also striking the moon, which reflects them to us as "moonlight."

One of the most remarkable of ancient astronomers was Aristarchus (Ar-iss-tark′-us), who actually put forward the correct idea that the earth is in motion, spinning like a top and also circling around the sun.



Hence, the reason why we seem to see the sun going round us from east to west is that we are on a huge sphere, the earth, which is turning in the opposite direction—from west to east. This makes the sun (and the other heavenly bodies) *seem* to be going round us the other way.

Suppose you were on a very large boat that could sail along without making a sound or a ripple. If you looked out of a porthole and saw a light far away, moving around you from east to west, you might easily imagine that you were stationary, and that the light was doing the moving. Sometimes people sitting in a train at a station see on the next track a train which is apparently moving by them in the opposite direction.

Then they discover that it is their own train which had started forward, and which thus seemed to make the one they were looking at go past them the other way. Or sometimes they see it is their train which is standing still, though they thought it was moving because something went by them.

Although Aristarchus' idea was right, it was rejected by most ancient astronomers. However, this same idea was arrived at by Copernicus (Ko-per′-nick-uss), the founder of modern astronomy, who lived in Poland in the late fifteenth and early sixteenth centuries (1473-1543). In his day, too, it was ridiculed, and even thought dangerous. It takes courage as well as logic to keep on working to show that something is right which the people around you regard as wrong. Copernicus was strengthened and encouraged in his efforts by finding there were others before him who had held the idea that the earth was in motion.

Another remarkable conclusion reached in the world of ancient Greece was that of Anaximander (An-ax-im-man′-der), who advanced the idea of evolution—that is, that new species of animals could come about by gradual changes in the earlier forms. This notion also did not take real hold until much later, in the nineteenth century, when Charles Darwin gave it a substantial basis of detailed evidence.

## PHILOSOPHY AND SCIENCE

These are but a few examples of the brilliant pioneering work done by the Greeks of old. It is interesting to note, by the way, that these men all called

themselves philosophers. Philosophy meant the pursuit of truth, in whatever field. In fact, it was not until about the eighteenth century, when specialization became increasingly organized, that people began to speak of "sciences" as being different from philosophy, and those working in such fields began to refer to themselves as scientists rather than philosophers. Thus philosophy is a sort of mother of the sciences. It continues to give rise to new branches of knowledge, and to deal with certain questions that are important to all branches.

These Greek philosophers also worked out many pioneering ideas in social fields, like government and economics. They were among the first to be convinced that social problems, as well as physical problems, could be dealt with by reason, by the method of logic. They had a firm belief that principles and laws could be found in man's social world, as well as in the rest of nature.

Thus, they analyzed forms of government, economic practices, and ways of social life as eagerly as they did the movement of stars or the composition of matter. Some of them traveled to foreign countries, where they collected not only examples of plants and animals, but records about laws and customs as well.

We may be particularly interested in the fact that the earliest forms of democratic government which had real importance were developed in the Greek world. Especially famous was that which existed during parts of the sixth and fifth centuries B.C. at Athens. Although it was a quite limited democracy

(for example, it never abolished slavery), it was of immense pioneering importance. An idea must be born before it can grow.

Thus natural and social sciences were born, and began to grow in remarkable fashion. But, as it happened, there came a sort of slow-down in the rate of growth for a long, long time. Then, speed was picked up again, far beyond expectation—all of which makes another part of our story.

CHAPTER

# 3

# Slow-Down For A Thousand Years, And Then Real Progress

## ROME AND THE DARK AGES

After these brilliant beginnings in the ancient world, a strange thing happened. For centuries further progress was not made, and even the very existence of the Greeks and their achievements became almost forgotten by Europeans, like some magnificent and abandoned foundation over which the dust settles.

Leadership in the world as it then existed had passed from Greece to Rome. The Romans, of course, saw and knew of all the work of the Greeks in the different fields of art and science, and carried on some of it with great success themselves. They were especially noteworthy for their contributions to the field of law.

For example, the Emperor Justinian (Juss-tin′-ee-an) is famous for the fact that he had all the laws

"codified," that is, organized and written down in clear language. Thus Roman law, through his Code and in other respects, became the basis for much of European law, and remains so to this day. This emperor lived in the sixth century (between five and six hundred years after the birth of Christ). He ruled from Constantinople, after Rome's decline in the West.

At that time the people of western and northern Europe—in fact, of practically all of the rest of Europe—were quite uncivilized compared to the Romans. The Roman Empire held in subjection territory now within countries like Spain, France, Germany, Belgium, the Netherlands, Britain, and others. In the course of time, these peoples were able to throw off their Roman conquerors and to build up their own power.

But in doing so, they did not pay particular attention to the scientific and artistic creations, which had come mostly from the Greeks, and were to be found among the Romans. Many of the books, records and objects of art were destroyed. Very little thought was given to the preservation of important documents. To make matters worse, printing had never been in use, so that books full of precious knowledge existed in relatively few copies, done by hand.

In fact, we would know far less today about the accomplishments of the ancient Greeks if non-European scholars in the Near East and Middle East had not preserved various books and records, and translated them into the Arabic language. This pe-

riod, when western Europe was sadly ignorant of many great achievements of Greek civilization, and was therefore unable to make use of them, is often called the Dark Ages.

After centuries had passed, more and more of the splendid successes of the ancient world began to be rediscovered in Europe. What had been accomplished in that world seemed so amazing that for a long time teachers were content to do little more than pass on to each new generation of scholars the conclusions arrived at by leading Greek thinkers. There was little scientific progress beyond that of the Greeks until around the fifteenth and sixteenth centuries.

However, when the fruits of Greek talent in various fields had once more been understood and digested, real progress once more took place. This whole process became so important to the life of Europe that the historical period from around the fourteenth to the seventeenth century is called the Renaissance (Ren-ess-ahnss'), a French word meaning rebirth. (This period is considered to mark the end of the Middle Ages and the beginning of modern times. The Middle Ages, or medieval times, are so called because they come between ancient and modern times.) In other words, the whole pursuit of knowledge took on new life, and science began to grow again.

## THE EARTH AND THE UNIVERSE

The most dramatic sign of the rebirth of a scientific spirit was the work of Copernicus, to which we re-

ferred in the last chapter. In fact, the effect of his work was so powerful and so disturbing that it is often called "the Copernican Revolution." And it was not altogether a bloodless revolution, as we shall see.

Imagine for yourself the situation of people who lived at that time. Practically everyone, including the most highly educated teachers and the most powerful leaders (and all of their ancestors for more than a thousand years back), had believed that the earth was stationary—as indeed it seems to be by ordinary observation. And they believed not only that it was stationary, but that it was the center of everything.

For does it not seem that practically everything revolves around this earth of ours? The sun appears to circle us daily, rising in the east and setting in the west. So does the moon. And most of the stars also seem to stream around us in the same sky procession from east to west every night.

Man thought of his world as majestically motionless among the stars and planets of the universe, while almost everything else moved respectfully around it and him. Moreover, he thought of the universe (that is, the total system of stars, planets and everything else in space) as quite small. He felt that it could all be seen with the naked eye. The telescope had not yet been invented, so men naturally assumed that there was no more to be seen than what people had always seen.

In fact, this whole idea of the universe, and the supposed central place of our earth in it, seemed com-

pletely "natural." So it is no wonder people were shocked when Copernicus told them it was all quite different.

He told them that the earth was not stationary, but was rotating like a top and at the same time revolving around the sun. He also told them the earth was not the center of the universe. Our globe, he explained, was one of a number of planets, each of which was circling around the sun at a different distance from it. In other words, some planets are nearer the sun than others, but their orbits (or paths of motion) all go around the sun.

Not only is the earth not central. It is also not very large compared to the sun. (In size or bulk the sun is actually more than a million times larger than the earth, as we have learned since Copernicus' time.) The sun is really a star—the star nearest to us—and of course it is aflame, burning with such intensity that it lights and heats us across millions of miles of space.

As far as we know, many stars may have planets circling around them. Our instruments are as yet not powerful enough to tell, for planets belonging to other stars would be difficult to detect, being relatively small and, perhaps, not aflame themselves.

The system of astronomy that had been generally accepted for more than a thousand years was that of Ptolemy (Tall′-em-ee). He was a Greek living in Egypt, who held that the earth was the stationary center of the universe. While many of the observations and calculations which he and his followers made

were of real scientific value, his *explanations* of these things were wrong in some of the most important respects.

This sort of situation often comes about in the history of science. For example, very exact and valuable observations may be made about the symptoms and course of various diseases, while there is as yet no idea, or a false idea, about the basic cause of these illnesses. For centuries many aspects of diseases like smallpox, consumption and cholera were accurately recorded, while the existence of microbes as a cause was unsuspected.

What was wrong with Ptolemy's explanations, from the viewpoint of science? It is not hard to see the answer to this question, and it reveals something of great importance concerning scientific method.

Copernicus pointed out that he had a *simpler* explanation than Ptolemy for the motions that could be observed. That is, he could explain them in a way that made *fewer assumptions*. An assumption is, of course, an unproved statement. Therefore, the fewer assumptions you make, the less likely you are to be wrong; the more assumptions, the more chance for error, other things being equal.

Ptolemy *assumed* the earth was stationary. Copernicus *assumed* it was moving. So far, each has made one assumption. However, assuming the earth is motionless, Ptolemy could give no satisfactory reason why so many things moved around it as a center. He had no way to *explain* what could be observed—that the sun, the moon, and countless stars seemed to keep going

round and round the earth from east to west. Why the same direction for all? Why the same center for all? He simply assumed that in each separate case the east-west motion around the earth was the *true motion.*

But, one might ask, why is that an *assumption?* Isn't that what we see, and isn't it therefore a fact? If we stop to think, we realize that this is not necessarily the case, just as Aristarchus the Greek, seventeen hundred years before Copernicus, realized it.

For, as we said in the preceding chapter, when we see distant lights moving, it does not necessarily mean that we are standing still and that the lights are moving as we see them. It may mean that we are moving the other way, and the lights are stationary. Or it may mean that both we and the lights are moving in different directions. Or it may even mean that both we and the lights are moving in the same direction, but at different rates of speed.

If there is any doubt about this, let us go back to the example we discussed in the last chapter, and add some conditions: Suppose you were on a large ship in a perfectly calm sea, out of sight of land, and had no way of telling whether you were moving or not. Suppose that all you saw was another ship in the distance, passing you from west to east at twenty miles an hour. Your first impulse would probably be to conclude that you were stationary and the other ship was in fact moving east at twenty miles an hour.

But if you began to think it over, you would realize that your first explanation was not *necessarily* correct.

It is only *one* assumption; and there are several others that might just as easily be true, that are just as probable in view of what you observed:

1. The other ship is stationary, and you are moving *west* at twenty miles an hour.

2. Both ships are moving, but in opposite directions—yours west and the other east, each at ten miles an hour (or at any two speeds which add up to twenty).

3. Both ships are moving east, but the other ship is going twenty miles an hour faster than yours.

Any one of these situations would result in your "seeing" the same thing: the other ship moving east past you at twenty miles an hour. In fact, before you read the next sentence, try to think of still another situation which would give the same result. How about this one: Both ships are moving west, but yours is going twenty miles an hour faster? Wouldn't that also make the other ship seem to go eastward at twenty miles an hour? (Probably at this point we ought to make an apology to real sailors, who would never speak of "miles an hour" at sea, but of "knots." A knot is one nautical mile per hour.)

Now the whole point is this: The assumption Ptolemy made—that the earth is stationary—didn't explain anything else. It didn't explain a single one of the multitude of observed "east-west" motions. For every star and planet that seemed to go from east to west, Ptolemy had to make an additional assumption—that this was its true motion.

However, Copernicus' assumption—that the earth

was rotating from west to east—explained *all* the thousands of observed motions that seemed to go from east to west. It explained why all the bodies appear to be moving in the *same* direction, around the *same* center. It accounted for what Ptolemy could not account for. Or, to put it more exactly: By making one assumption it accounted for what Ptolemy could only explain by making thousands of assumptions.

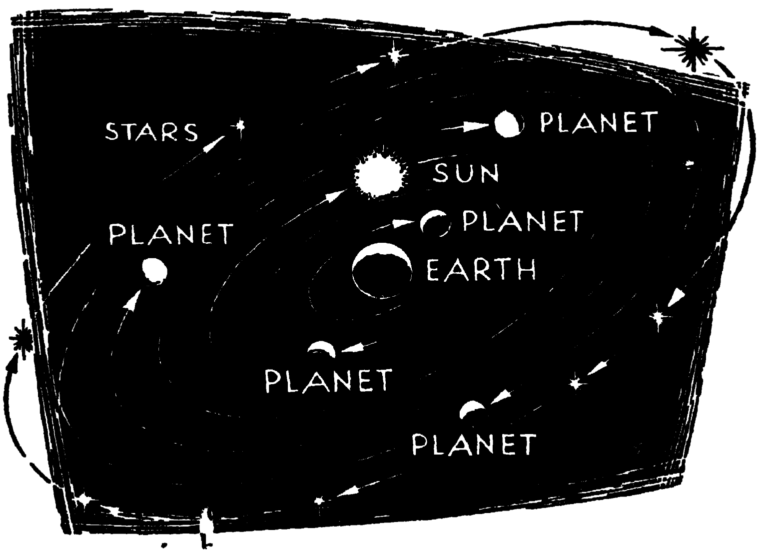
There were, of course, other sides to this problem and other kinds of evidence. We are considering here but a few of the basic points and the general nature of Copernicus' work.

He showed, not only that the earth's rotation from west to east, finishing one complete spin every twenty-four hours, explained all the apparent "east-west" motions around the earth in each twenty-four hours. He also showed that, while our globe rotates, it travels in a vast orbit around the sun, completing its revolution once every three hundred and sixty-five days. The constant spinning or rotation gives us day and night, just as the continuous circling or revolution gives us the seasons of the year.

As time went on, other thinkers built higher and higher on the great foundations laid down by Copernicus. We now know not only that our earth is a spinning globe circling around a flaming star, but that this star, or sun, itself is moving through space. It is traveling toward a northern group of stars, called Lyra, at about twelve miles a second, followed by its family of planets, each like the earth circling around

PTOLEMY—*Explanation of daily motions*

*(accepted from ancient times to 16th century)*

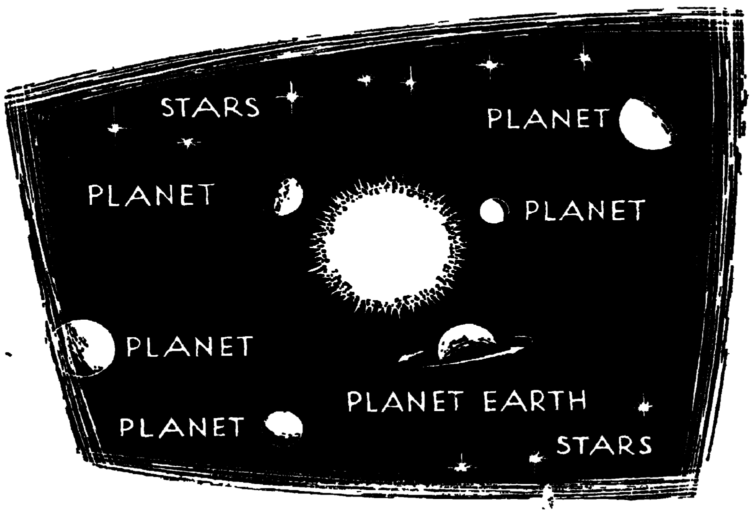



1. Everything thought of as going around a stationary earth from east to west.

2. In each case visible motion assumed to be true motion. No explanation why all bodies should go around the earth.

*Explanation of daily motions—COPERNICUS*

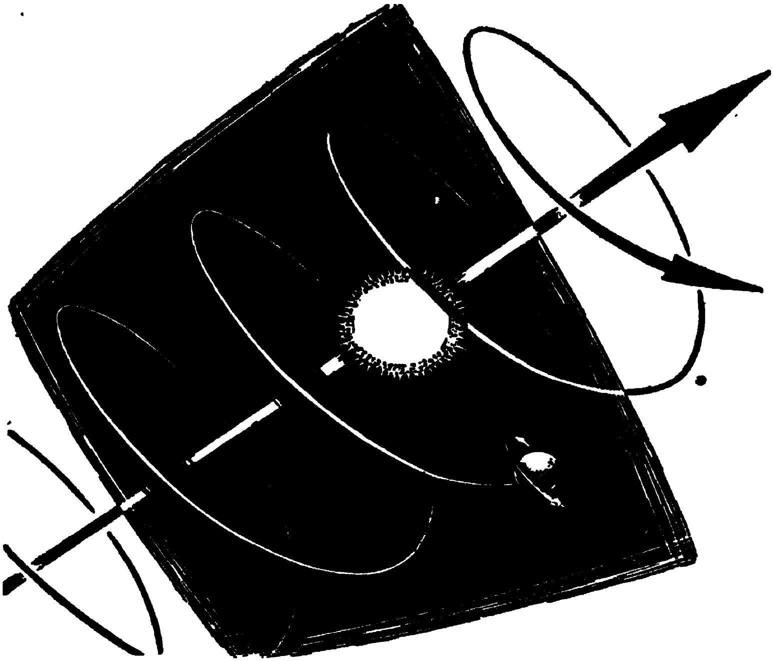
*(basis of modern astronomy)*




1. Earth spins like a top from west to east, making everything else seem to go around us from east to west.

2. This one assumption explains all the risings in the east and settings in the west each 24 hours.

(Yearly motions not shown in these diagrams.)



General type of motion of any planet, such as Earth, as it travels around the Sun in a yearly orbit and follows it through space. The forward speed of the Sun is about 12 miles per second. We get our measure of a "year" from the time it takes the Earth to complete one circular journey around the Sun.

the leader. (The orbits of the planets are, in fact, not exactly circles, but ellipses—that is, paths resembling ovals.)

Our sun is indeed somewhat like the leader of a little parade of spheres through the sky. But the paraders, instead of going in a straight line behind the leader, keep circling around him. Thus the smaller

spheres, the planets, keep swinging around the sun, as they follow it. Some circle in narrow orbits, others in wider ones, and each at the same time spins like a top. Our earth is the third planet outward from the sun. And there is a still smaller body, the moon, which follows us, at the same time circling round us, as we follow the sun and circle around it. That is why the moon is called a "satellite" (dependent or follower) of the earth. The moon seems larger than the stars only because it is so much nearer to us.

All the stars are moving, too, though they are so far away that, in the few thousand years we have been carefully observing them, they do not seem to be any closer to or farther away from each other, in spite of their great rate of speed. There are billions upon billions of stars, perhaps also a large number of planets and satellites, all moving through space, with plenty of room to spare.

Stars and planets die away, and new ones are formed over periods of time so long that we can hardly imagine them. The "life span" of these bodies is measured in billions of years, and more. It makes us feel proud to be a part of something so immense in every way. And it is thrilling to realize that in a little portion of that immensity, on a small globe, there is a tiny creature, man, who by the use of his reasoning power has discovered many marvelous facts about the universe in which he lives—and will undoubtedly discover more and more. To mention only one example, the idea of man traveling off his planet and beginning to explore other planets, is no longer a

fanciful dream, but comes closer and closer to a scientific possibility.

This universe is rich beyond imagination in all kinds of possibilities. No matter how much we find out about it, we may be sure there will always be more to discover and explore; we shall never lack for adventure. However, when Copernicus first explained his conclusions, people hardly had the courage to believe him. They were shocked and frightened by the idea of such a universe. For some time it was even considered dangerous teaching, contrary to religion; and some of those who taught it were persecuted, imprisoned, and even put to death.

In this way the spreading of scientific truth was delayed, but it was not stopped. There is a legend about Galileo (Gal-ill-lay′-o), the famous Italian astronomer, who was persecuted by the Inquisition in the seventeenth century. When he was forced to deny his statement that the earth was in motion, it is said he muttered, as he left the scene of his trial: "Nevertheless, it does move."

## THE APPLE AND THE MOON

By the time that Isaac Newton, an Englishman of the seventeenth and early eighteenth century, had proved his Law of Gravitation, not only astronomy, but physics as well, had a good start. Physics makes a study of laws of nature that apply to all physical objects; and the laws of motion have an important place among them. Newton, born in 1642, the very year that Galileo died, explained a great deal about mo-

tion when he showed that every object or bit of matter attracts every other object (that is, each object makes the other move toward it) with a force that increases and decreases in the following way:

1. The heavier any object is, the more power it has to attract other objects. The lighter the object, the less power it has to attract others.

2. The closer the object is to any other object, the greater is the force of attraction. The farther away the objects are from each other, the less is the force of attraction.

This is the principle of gravitation.

Thus Newton explained the basic reason why an apple falls to the earth, and why the earth revolves around the sun. In other words, all bodies are somewhat like magnets, with power to attract. The earth is so heavy compared to the apple that it pulls the apple to it; and the sun is so heavy compared to the earth that it pulls the earth toward it, and keeps the earth revolving around it.

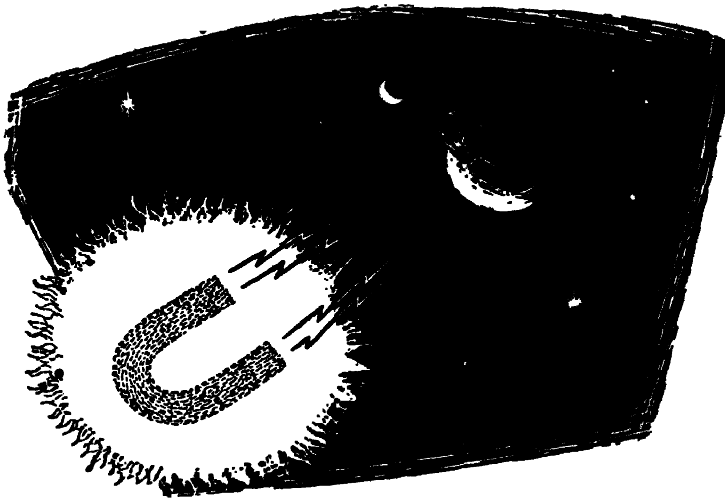
But why doesn't the earth tumble onto the sun, just as the apple falls onto the earth? Perhaps you can answer that question, at least partly, from what we have already said: The force of gravity is not only pulling the earth toward the sun. It is also pulling the earth away from the sun, toward other large bodies, such as nearby planets and stars. But the other stars are much farther from the earth than the sun is, and the planets are much lighter in weight than the sun. Therefore, their gravitational power to attract the earth is weaker. This is one of the reasons why the earth keeps follow-

ing and circling around the sun, but does not fall onto it.

If we were able to move stars and planets at will, we could set them in such a path that an apple would not fall to the ground, but would keep on circling round and round the earth (between the earth and the other bodies), just as our moon actually does. The motion of any object is a result of the forces acting upon it.

### FORMS OF LIFE

Mathematics had been given a good start in the ancient world, as we said in the preceding chapter, and it was further developed, in its different branches, during the Renaissance. When astronomy and physics also had good solid foundations, chemistry and other



physical sciences could be built up in a substantial way. While it is not our purpose to give anything like a complete history of science, in these few pages, there is another development which should be mentioned, one of tremendous importance to biology and the life sciences.

Biology is the study of all living things, of the laws which govern the processes of birth, growth, and death. Sciences closely connected with it are zoology, which concentrates on animal life, and botany, which concentrates on plant life.

Men had been interested in these fields ever since ancient times and had made many observations and classifications. But it was not until the middle of the nineteenth century that these sciences were given a basis upon which great progress could be made. It was then that the English scientist, Charles Darwin,

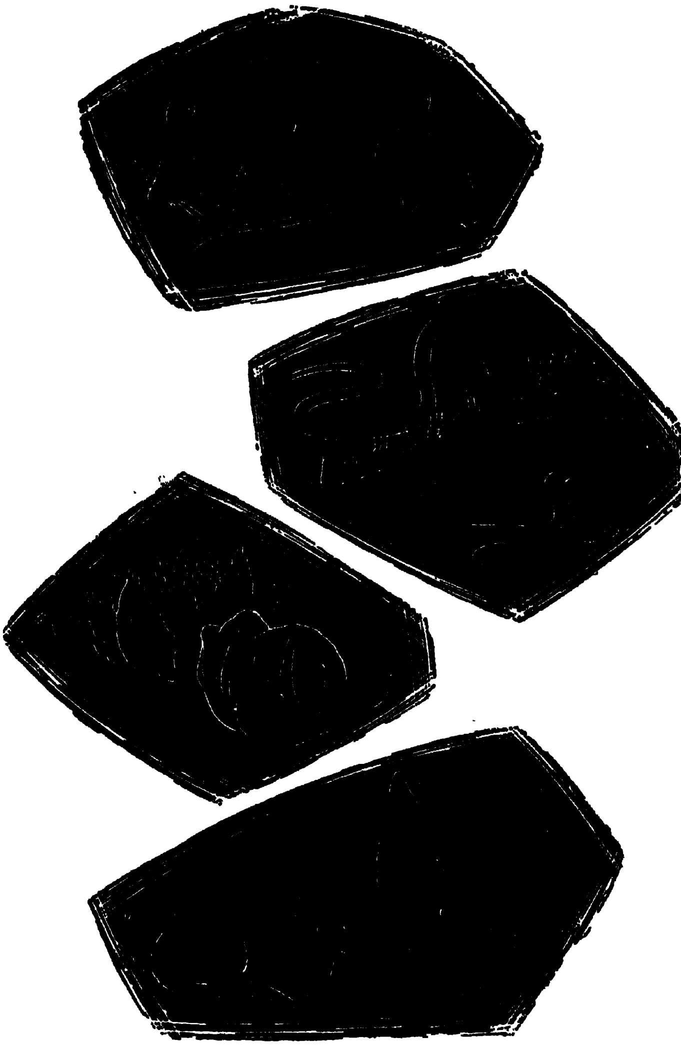
gathered enough evidence to provide substantial proof for his theory of evolution.

Every scientific theory is an answer; but before there is an answer, there must be a question. To understand the answer it is always a good idea first to be clear about the question. The question to which evolution is an answer might be put this way: How does it happen that there are so many different species of plants and animals? Were there always just as many as there are now, or is it possible for new species to develop out of the old ones?

As we look about us in the world, we see many varieties of living things—dogs and cats, crows and canaries, daisies and pine trees, earthworms and rattlesnakes, goldfishes and sharks, men, women, and children. We know, of course, that we can get new dogs from dogs, new daisies from daisies, new people from people, and so on. Each species can produce more and more new individuals of its own kind. But the question is this: Can a species in any way give rise to a *new species?*

As we saw in the last chapter, the idea that such a thing must be possible was suggested by Anaximander in ancient Greece more than two thousand years before Darwin. It also occurred to a number of later thinkers. For practically any species, whether animal or plant, is so similar in appearance and structure to certain other species that it suggests that they are relatives of some kind.

For example, the mouse resembles the rat, and the cat resembles the tiger. Snakes that live on land resem-



ble eels that live in the water. A head of cabbage resembles a head of lettuce. Long before Darwin, scientists had worked out a system of classifying all known species of plants and animals. As a result, they could see that each species wac only slightly different from the next in appearance and formation. This was sometimes called the Tree of Life, and it indeed suggested a "family tree."

However, Darwin was the first to offer substantial evidence of family relationship. He showed how certain members of a species might undergo various changes, so that, over a long period of time, they could develop into a new species. These changes could be traced partly to differences in environment (conditions of climate, food supply, and the like), and partly to the workings of heredity, by which it is possible for offspring to have new and unusual traits, different from their parents. In any species those members whose traits are best fitted for the particular environment have the best chance of surviving and of producing offspring.

Once the idea of evolution took hold, new kinds of evidence were found by many scientists. Remains of species which no longer exist, such as dinosaurs, were discovered in the earth and rocks. Evolution helped to explain why certain bodily organs, like man's appendix, continue to exist although they are no longer necessary. That is, such organs may once have been necessary for survival, under different conditions. It also helped to explain the different stages of development through which a human embryo goes within the

womb, before birth. These stages are a repetition of the stages of evolution which the species as a whole went through as it developed.

The discovery of evolution, like the discovery of the movement of our earth amid the countless swarming stars, or the releasing of the immense energy contained in the tiny atom, is one of those scientific findings which open up all sorts of new possibilities. It points to new paths of knowledge to explore, and new kinds of power to attain. In other words, we live in a universe that is moving, changing, developing, and growing. It is a challenge to us to develop and grow with it. The universe is not static and small, as people thought for centuries, but dynamic and immense. New species can be produced; new energies can be released; new worlds can be discovered. We may certainly be thankful for all this, because only that which changes can progress.

In the nineteenth century, another type of science, of tremendous importance to man, began to emerge—the science of society. That story deserves a chapter by itself. However, before we come to it, there are some important matters on which we must be clear. We should make sure that we can answer the question in the chapter heading on the next page. To some that may seem easy, but there is more to it than might be suspected.

CHAPTER

# 4

# What Makes Science Different From Other Forms Of Knowledge?

## DEFINING SCIENCE

In order to understand a certain thing, we must be able to tell what makes it like other things, and also, what makes it different. A baseball, for example, is in some respects like any other ball used in sports: It is not flat, it has a certain amount of bounce, and it is light enough to be thrown or hit by players. But of course, there is something different about a baseball. Otherwise, it would be impossible to tell it from the ball used, for instance, in tennis or golf. A baseball has its own kind of material, stitching, size, weight, degree of hardness, and so on.

So far in this book we have been talking about science mostly in a way which shows how it is like any other form of knowledge. Now let us look at the

other side of the question: What makes it different? In other words, it would certainly be correct to say that all science is knowledge, but it would not be correct to say that all knowledge is science. Anyone can see this from the following examples.

Suppose, as I sat at my desk, I saw a piece of thread on the floor and picked it up. I might examine it carefully and then write down in my notebook: "At 10:05 A.M. I picked up a piece of thread which was light blue in color and exactly three inches long." Now this would certainly be *knowledge*. My statement would be perfectly true, and everything I said in it would be an actual fact. But if I called it science, you might well object. Why?

The first reason is, of course, that it is just a single item of knowledge. You don't have to be a scientist to know that science must be a whole collection of truths, not just one fact by itself.

Suppose, then, that I gathered thousands or even millions of facts of that kind, and showed you dozens of notebooks filled with such statements as: "At 10:06 I found a broken yellow pencil which weighed half an ounce." "At 10:07 the sun went behind a cloud for 37 seconds." Would you then say that I had a science, even assuming all my statements were true? You would not need to be a scientist to feel that something more was wanted.

You would probably feel that science should not only be a collection of facts, but that the facts must be *organized*. They must be connected with one an-

other in such a way as to explain things and solve problems.

If the facts I collected did not solve any problems unsolved before, you would be quite right in denying that I had as yet made any contribution to science. The facts would still be facts, but they would be no more than that. To have science, you must have an *explanation* of facts, a *solution* of problems.

Science, then, is a body of knowledge based on facts, organized in such a way as to explain the facts and solve problems. Now, would that be enough to define a science? It might be, if understood in the proper way. But there is still a booby trap that must be avoided. Let us see what it is.

### THE CASE OF "WATEROLOGY"

Suppose I said: I am going to build up a body of organized knowledge based on facts, which will explain things and solve problems. It is a new science, concerned with water, and therefore I shall make up a new name for it—Waterology. After all, there is nothing wrong with having new sciences. (On the contrary, the more the better, provided they are genuine.) And for a new science it would be proper to have a new name. So far, so good.

Now suppose I proceeded in the following way: First I divided water into fresh and salt, and then I classified the bodies of fresh water in which I was interested under the following headings: lakes, ponds, rivers, brooks. Bodies of salt water I put into the fol-

lowing classes: oceans, seas, lakes (a lake can be fresh or salt). Then I noted which countries of the world had the most of each of these classifications, either within the country or along its coasts. I calculated first, according to number of bodies; second, according to amount of water.

This part of my new science I called World Waterology, and from it I drew the following conclusions:

1. Under similar conditions, the bigger a country is, the more likely it is to have numerous bodies of water. This I called the Law of Size-Number Relation.

2. The farther inland a country is, the more likely it is to have bodies of fresh rather than salt water. This I called the Law of Fresh Water Location.

3. The more coastline a country has, the more deposits of salt water will tend to accumulate. This I called the Law of Salt Water Deposits.

Then I turned my attention to our own country. I made several lists of the 48 states, some of the lists being for fresh water, and some for salt. On the fresh water side, proceeding as I had in World Waterology, I placed the states according to the number of bodies in each classification—lakes, rivers, and so on.

Then I listed them according to the amount of water in each classification, calculated from the known measurements of each body. On the salt water side, I listed the states according to the extent of coastline washed by salt water, and also according to the amount of salt water within the state.

This part of my science I called National Waterology, and from it I drew these conclusions:

1. In most cases, longer rivers are deeper than shorter ones. This I called the Law of Length-Depth Relation.

2. The farther a state is from a seacoast, the less likely it is to have any salt tidewater in its rivers. This I called the Law of Distance of Tidewater Rivers.

3. Fresh lakes are not normally fed by sea water, but a lake can be salt without being fed by sea water (Great Salt Lake in Utah, for example). This I called the Law of Fresh and Salt Lakes.

The remaining part of my science I termed Local Waterology. In this I investigated the amount of water used in individual towns and cities. These were my conclusions:

1. On the average, the greater the population, the more water is consumed. (Law of Variation in Water Use by Population.)

2. In places where the use of water is taxed according to amount consumed, the average household uses up less water. (Law of Decreased Consumption of Taxed Water.)

3. There is a universal preference for fresh water as opposed to salt water for general household use. (Law of Preference for Fresh Water.)

Such is "waterology." Even supposing all its statements are true, and all its facts correctly reported, would you call it a genuine science? You probably

would not, even though you yourself might never have studied science in any systematic way.

### WHY NOT A SCIENCE?

But why is such knowledge not a genuine science? The interesting thing is that at first glance it seems to fit well enough the definition we previously agreed upon: A science is a body of knowledge based on facts, organized in such a way as to explain the facts and solve problems.

Take the definition point by point. Waterology is certainly knowledge based on facts. All of its statements are true, or could easily be made so with slight adjustments. And it is certainly organized. The various facts are divided and classified in an orderly and understandable way, and the study proceeds systematically from the larger units to the smaller ones.

Does waterology explain facts and solve problems? It seems to explain certain facts and solve certain problems. For example the larger proportion of salt tidal water in rivers is explained by nearness to a seacoast. The decrease in consumption of fresh water in certain localities is explained by taxation. It solves such problems as: What countries or states have more bodies of water than others? What countries or states have greater amounts of water than others?

Should waterology, then, be recognized as a new and genuine science? What *is* wrong with it? To test the claim of any organized body of knowledge to be a new science, we must raise two questions:

1. How much do we now know that we did not know before?

2. How much can we now do that we could not do before?

Waterology fails the test in answering both these questions. In the first place, it tells us almost nothing that we did not know before. We already knew that bigger countries have more bodies of water than smaller countries under similar conditions; that the closer a river is to the seacoast, the more likely it is to contain salt water, since the tides flow in and out; that when the government taxes the use of water, less of it is used; and so on.

Those who did not know such facts could easily find them in the existing sciences or in general collections of knowledge. Thus any problems which waterology is capable of solving are already solved without waterology. Any facts waterology is capable of explaining are already explained without it.

### THE PLACE OF PREDICTION

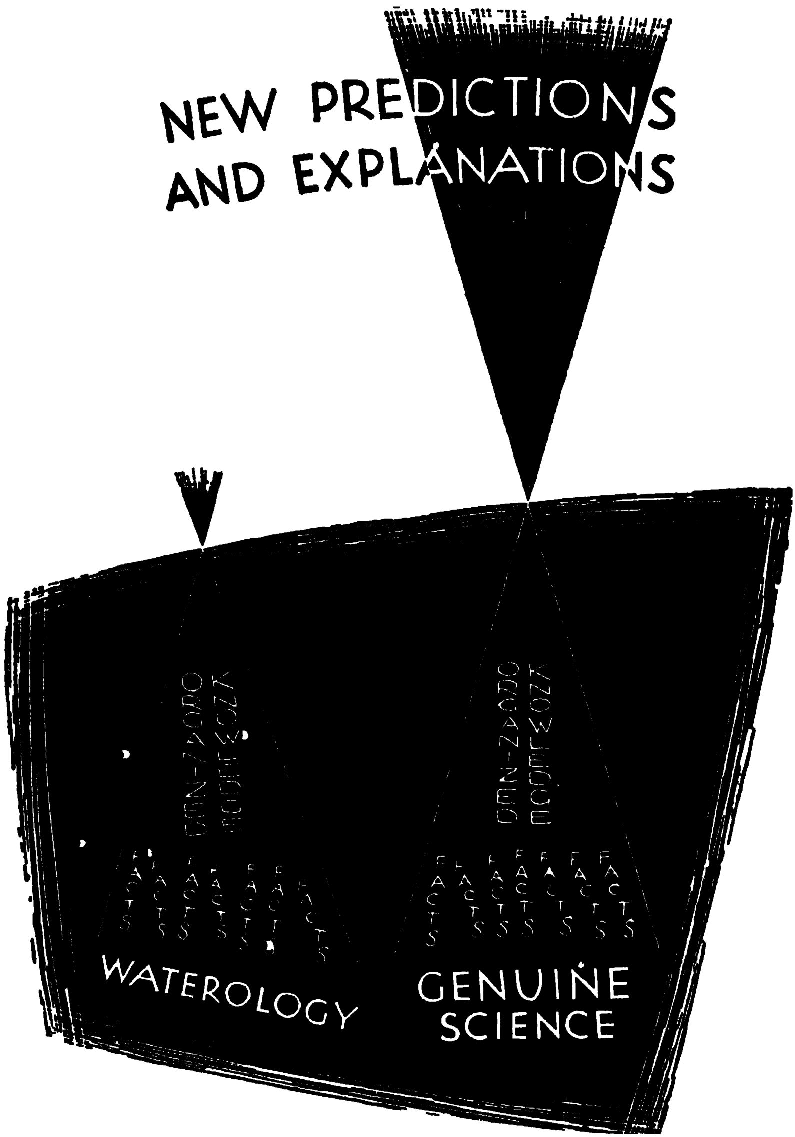
The same applies to what can be *done*. How much does waterology add to our ability to predict or control water, in regard to any of its properties or behavior? It does not enable us to do anything with water, to water, or about water that we could not do before. This part of the test is very important. Even if the facts collected and the conclusions arrived at were *new* or previously *unknown*, we would still have to ask: What can be done with them?

For a science is not created just by gathering facts

that were never gathered before, and drawing conclusions never drawn before, no matter how numerous or how well organized they may be. The facts and conclusions must be such as to add a good deal to our ability to predict and control. For example, suppose waterology were able to tell us the exact width of every brook at every point of its course in every state of the United States on every day of the year 1898. We would then know thousands of truths that are unknown now. But we would hardly have improved our sciences in like degree.

A scientist is not interested in dealing with facts just because they are facts, or just because they were unknown before, any more than an artist is interested in painting scenes just because they are scenes, or just because they were never painted before. In each case, there is a principle of selection at work. The scene must be significant, and so must the fact. In art, it may be that the scene brings out an emotion or feeling of some kind, or recalls some important event. In science, the fact must help to explain something that could not be explained before; it must help to predict and control in a way that was not possible before. Neither in science nor in art is mere *newness* enough.

However, it should be emphasized that waterology is not at fault simply because it is new. There is nothing wrong with having new sciences. More and more will undoubtedly be created as time goes on, even as psychology, for example, is now being built up. Only, of course, they must be genuine sciences. They


NEW PREDICTIONS
AND EXPLANATIONS
ORGANIZED KNOWLEDGE
ORGANIZED KNOWLEDGE
WATEROLOGY
GENUINE SCIENCE

must not only be organized bodies of new knowledge. They must be organized bodies of new knowledge of the kind that add signficantly to our ability to explain, predict, control.

We are now in a position to make a fuller and more exact definition than before. A science is a body of organized knowledge, based on facts, which increases in large measure our ability to explain and predict.

By the way, a good deal of that kind of knowledge about water already exists, in such known sciences as chemistry, physics, geology, geography, and oceanography. The knowledge that can be found, concerning water, in sciences like these is no more *true* than the knowledge found in waterology. By count, there might even be more facts, more truths, collected in waterology.

But think how much more prediction and control are yielded by the truths of chemistry and physics than by the truths of waterology. How much could the "waterologist" predict that the average person could not predict, in spite of the fact that he never heard of waterology? Practically nothing. But the answer is very different if we compare the average person with the chemist.

Ask the "waterologist" and the average person to predict whether the use of water will increase or decrease if it is taxed, and you will undoubtedly get the same answer from both. You will also get the same answer from both if you ask them to predict whether the use of water will increase or decrease when the

population increases, or whether a greater amount of tidal salt water will be found in a river closer to the sea, or practically anything concerned with the facts or laws of waterology.

Now ask the chemist and the average person to predict in problems the chemist deals with, concerning water. For instance, give each a sample of unclear water, and ask them both to predict whether or not the water will kill a person if he drinks it; or, whether or not the water will give a person a certain disease. The chemist will analyze the water, and be able to make predictions of high accuracy. The person who knows nothing of chemistry will be helpless.

If the water does contain disease germs or poisons, ask both the chemist and the person who knows nothing of chemistry to tell you whether or not certain substances will make the water healthful. Again, the person without a knowledge of chemistry is likely to be helpless, whereas the chemist is likely to make reliable predictions.

You will, of course, find the same situation in regard to a thousand other questions concerning water, whether the science is chemistry, physics, or any other which deals with some aspect of water. Ask a person who has never studied science to predict whether, under present conditions, a certain area will have more water or less in 25 or 50 years; what type of metal or construction will best stand the pressure of water; in how many years the water level along a certain coast will be six feet higher or lower than it now is; whether this or that type of treated water will help prevent

tooth decay, and the like. Those who have never studied science could in most cases make only wild guesses about such matters, whereas various scientists can make accurate predictions.

Thus, an important test of a science is the amount of prediction it is able to add to what we have without it. The various laws of nature and causes discovered by different sciences have given us tremendous powers to predict which we did not possess before. Newton's Law of Gravitation, for example, enables us to predict how any object will move toward any other object if not interfered with by outside forces. It tells us that the objects are attracted to each other in such a way that the heavier and closer the object is, the greater is its power to attract; while the farther away and lighter it is, the less is its power to attract.

In fact, by means of this law, scientists have actually been able to predict that a planet, previously unknown as such, would be found if telescopes were carefully pointed to a certain exact spot in the heavens. Can you see how this situation could have come about?

Observation showed that the distant planet Uranus was not moving in that regular path in which it ought to have been moving, according to the behavior of the other planets. What could account for the irregularity? Now Newton's law, as we just said, had told the scientists that one reason why planets circle around the sun at all is that objects attract one another in proportion to their mass, and the sun is much heavier than any planet. At the same time, the

planets of course also attract one another, and this, along with other forces, helps to keep them from being pulled into the sun completely.

The planets revolving around the sun according to the law of gravitation are therefore in a situation something like an astronomical folk dance conducted according to the following rule: The heaviest body is the leader, and all circle around him at different distances. But no one can go in and touch the leader as long as there are other bodies in the dance which are heavy enough to exert sufficient force in a contrary direction. The path of any one dancer, therefore, depends on the weight of the leader as compared to his own weight and the weight of those around him.

If, under these circumstances, one planet does not seem to follow the path it ought to follow according to the rules, and yet we feel sure that it must be obeying the rules, what would be the most likely explanation? There must be another planet somewhere nearby, which we had not noticed before, exerting enough force to account for the apparent irregularity in the movement of its fellow planet.

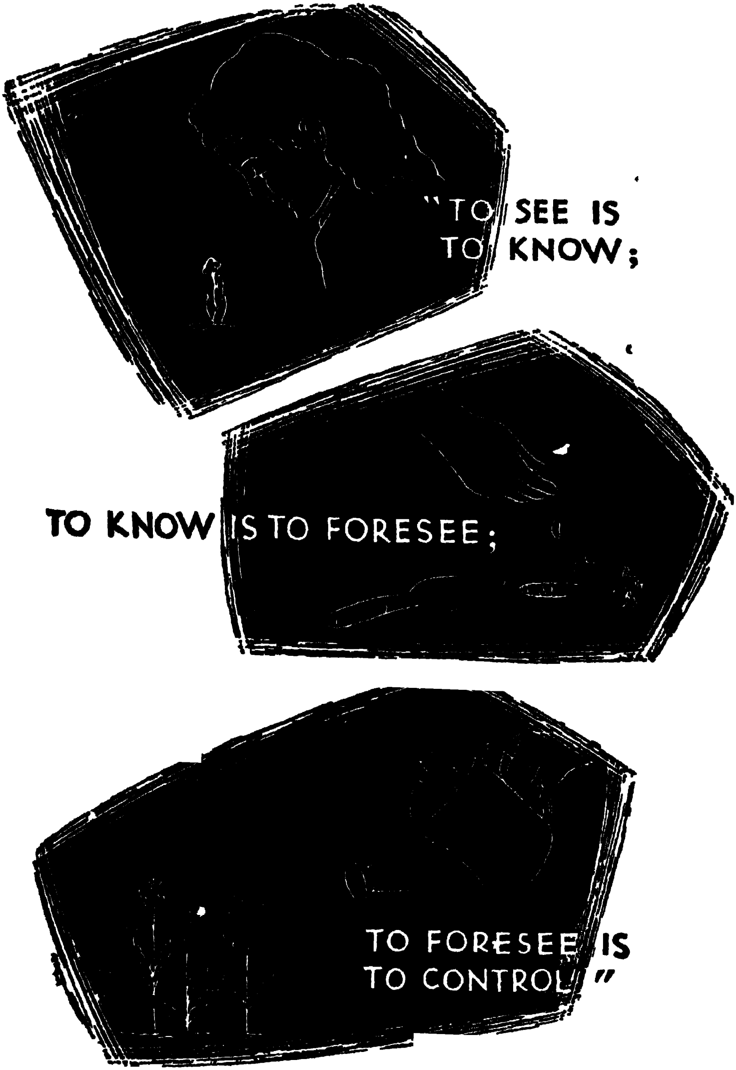
We know the law which the planets follow—that the path of motion depends on the relative mass and distance of surrounding bodies. Knowing the masses and distances of these bodies, we can map out the path the known planet should be (but is not) following. Thus we can see just how far off that path it is being pulled by the unknown body. Then we can calculate at what distance and of what mass an un-

known planet must be in order to exert just that much force on the known planet. And, after having made their calculations, the astronomers found it exactly where they had predicted! The new planet thus discovered in 1846 was given the name Neptune. In 1930 the same method aided in the discovery of a still more distant planet, which was called Pluto.

When scientists know the causes of disease and health, they can predict the conditions under which you will become ill and die or remain healthy and live. Because scientists know the laws of light, electricity, growth, or flight, they can predict the conditions under which it will be possible to obtain better light, harness electricity, improve growth, succeed in flight.

Thus prediction serves two important purposes in science. First, as we have seen, it helps us to find out whether or not our explanations are correct. If, according to the law or cause we think we have discovered, certain predictions can be made, but actual events turn out otherwise, then we know there is something wrong with our explanation—our law, cause, or whatever it is.

Second, prediction often leads to control. Whenever we are able to predict what will happen under such and such conditions, it helps us to gain the power of control over that happening. For then we know that wherever we can bring about those conditions, we can also bring about the happening; and wherever we can prevent them, we can help to prevent the happening.


"TO SEE IS
TO KNOW;
TO KNOW IS TO FORESEE;
TO FORESEE IS
TO CONTROL"

## WHY KNOWLEDGE IS POWER

It was that fact which Francis Bacon, a great pioneer of scientific method in the seventeenth century, had in mind when he made the statement that has so often been quoted: "Knowledge is power." In the nineteenth century a French follower of his, Auguste Comte, (Kont) had the same idea when he said: "To see is to know; to know is to foresee; to foresee is to control."

Even where prediction cannot lead to full and complete control, it is, in most cases, highly useful. For example, our ability to predict the movements of the heavenly bodies does not give us the power to stop them or to change their course. But perhaps you yourself can recall how we make great practical use of such predictions.

As we said in the early part of this book, once these movements could be predicted with regularity, it was possible for men in the ancient world to establish directions and divide time into years and days, hours and minutes. East is where the sun rises. A year is the amount of time it takes for the sunrise to occur again at the exact same point in relation to the stars.

In other words, our maps, clocks, and calendars are products of the knowledge by which we make accurate predictions in astronomy. Navigation is a practical application of the same knowledge. We are able to keep many a ship on its course and pilot many a plane to its destination, only because we can predict which stars will be at what positions in the sky as seen from the earth at a certain time and place. Thus we steer by the stars.

When we speak of "applied science" it is, of course, these same things we have in mind: all the different ways in which the knowledge gathered by the sciences leads to prediction, which in turn leads to some form of control or usefulness. But it should be emphasized that prediction is important not just because it leads to practical applications, but because it is a test of the truth of our theories and explanations. The more our predictions turn out to be wrong, the weaker our theory is. The more our predictions turn out to be right, the stronger our theory is.

Here we see another important truth: The question of whether a certain body of knowledge should be called a science is a question of *degree*. That is, the *more* this knowledge explains of that which could not be explained before, the *more* it predicts of that which could not be predicted before, the *more scientific* it is. It might even be said that any fact, however simple, if it is correctly reported as an item of knowledge, explains something and predicts something. At least, it explains that something exists or has existed, and predicts that it could be found if looked for under certain conditions.

But the whole point is, of course, that some facts explain far more than others. Some truths enable us to predict far more than others. And, as we have seen, what makes science different from other forms of knowledge is that it deliberately seeks and finds those truths which explain and predict more and more. How does it seek, and how does it find such truths? That is the story of scientific method. Let us turn to it next.

CHAPTER

# 5

# The Method Of Science: How It Works

### A BIRD'S-EYE VIEW

Let us go back to an example we used in the first chapter. Two children are discussing why a dog is licking a piece of paper. One says there must be something good to eat on the paper, though he admits he can see nothing of that kind there. The other has the theory that the dog probably likes paper itself. Then the first child seeks to disprove this theory and to prove his own by offering the dog clean paper. He shows that the dog has no interest in it, but keeps trying to lick the other piece of paper.

While this in itself is certainly not complete proof or disproof (for example, the dog might like paper, but might simply prefer one kind to another), still, it is a good start. Without knowing it, the child was using basic elements of scientific method.

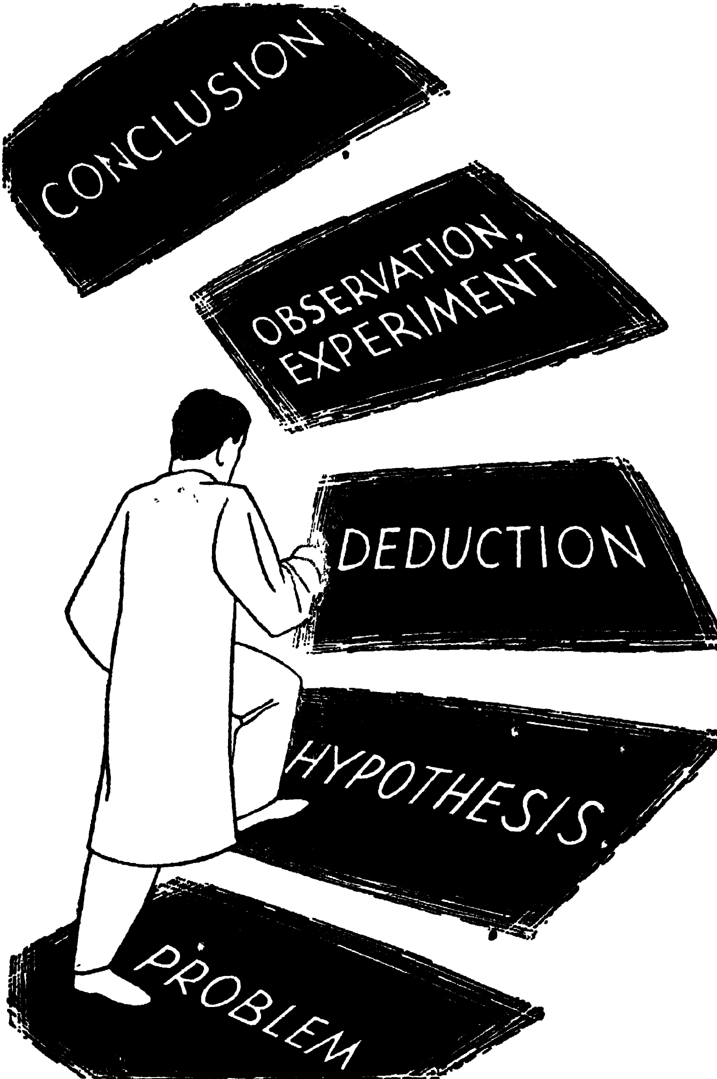
What did the child do? First, a problem was observed and expressed: Why is the dog licking the paper? That is Step One of scientific method: *Express the problem.*

Second, the child advanced a theory or hypothesis which he thought was the right solution of the problem: There was something good to eat on the paper. (Hypothesis is a technical term meaning an explanation, answer, or theory of some kind which is not yet proved.) Thus, Step Two is: *Propose an hypothesis.*

Third, he figured out what ought to happen if his hypothesis were right. The dog ought to reject the clean paper, but continue to go after the other. Notice that this reasoning took place *before* any experiment. We call this process "deduction." The child was "deducing" what ought to be true *if* his hypothesis were true. (Deduction is a technical term meaning the process of reasoning out what must necessarily follow if a certain statement is true.) Thus, Step Three is: *Make deductions from your hypothesis.*

Fourth, the child devised an experiment which would test his hypothesis. He took a piece of clean paper, offered it to the dog, and noted that the dog had no interest in it, but continued to go after the other paper. Thus, Step Four is: *Test your deductions by observations or experiments.*

Fifth, he concluded that the dog did not like paper itself, but was trying to eat something that must have been on the paper. Thus, Step Five is: *Draw your conclusion.*


CONCLUSION
OBSERVATION,
EXPERIMENT
DEDUCTION
HYPOTHESIS
PROBLEM

Such is a bird's-eye view of the method of science. Now let us examine in more detail how each of these steps works.

### THE PROBLEM

In the first step, it is important that the problem be expressed as clearly and concretely as possible. Otherwise, it is hard to do anything at all about it. Suppose, for example, you received a letter from someone, and all it said was, "I feel queer. Please advise me what to do." How could you possibly solve that person's problem on the basis of such a vague statement of what the problem is? It would be like trying to answer a question without really knowing what the question is.

The more you know about something, the more clearly and concretely you can express a problem concerning it. If a man's car will not go and he phones the nearest garage with the natural idea of obtaining some help to get out of his difficulty, the mechanic, just as naturally, will ask: "What's your problem?"

Why is it natural for the mechanic to ask such a question? Because, of course, if the problem is of one kind, he will have to bring one kind of equipment; if it is of another kind, then different equipment will be necessary. Is a tow truck needed, a battery charger, some gasoline, or what? Now, if the poor motorist knows little or nothing about the workings of his car, he will simply say: "I don't know what the problem is. You'll have to look it over."

On the other hand, the motorist may know enough

about automobiles to be able to say: "The battery works, but the fan is out of order." Or, "I have plenty of gas, but the battery is dead." Then, at least some kind of *problem* has been expressed. Whether it is the right one, or the only one in the situation, the expert mechanic alone will be able to say.

In other words, somebody whose car will not go, but who has no idea what is the matter with it, certainly has a *difficulty;* but he does not yet know exactly what his *problem* is. Unfortunately many people are in that situation about many things. Their first step must be to locate the problem. It is not always easy to do that, but it is absolutely necessary if scientific method is to be used successfully.

In the same way, it always helps, in studying science and trying to understand its solutions, to make sure you are clear about the problems, which are the starting point. Many people do not pay enough attention to this part of the matter. They are like a group sitting in a room listening to a person who is using the phone; they hear only what that person is saying. Suppose he is answering questions put by the party at the other end of the line. The group in the room would certainly understand something of what was being discussed. But they would understand a good deal more—and all of it more easily—if they knew exactly what the questions were. When you are puzzled about the solution, try to put the problem to yourself once again in clear language. When you clarify the question, it will become easier to understand the answer.

**THEORY AND HYPOTHESIS**

One of the most mistaken ideas which people have about science is the belief that the scientist "avoids theories and sticks to facts." Step Two of scientific method, the proposing or forming of an hypothesis, shows how far wrong this widespread opinion is.

Of course, a scientist does not call a theory true until it is proved true. But he deals with theories all the time. In one sense, that is the heart of his work, for his method is basically a process of proving that some theory is true or false. It is clear that before you can prove or disprove a theory, you must first have one. A person who insisted on avoiding theories would avoid science.

In other words, in order to go to work on a problem, the scientist must have some idea or other of a possible solution. That idea is his theory in regard to that particular matter. While it is unproved, it is usually called an hypothesis. (This word comes from a Greek term meaning, to *place under, as a foundation*. That is, it is a starting point from which the reasoning is built up.) The scientist makes observations and experiments to test his hypothesis, to see whether it is true or false.

Thus, without an hypothesis to work with, to work upon as a starting point, there would be little for the scientist to do. As we saw earlier, merely collecting facts does not make a science. The facts must be explained. The only way we can try to explain anything that has not been explained before is, first, to think up

an idea of what the explanation may be, and then to test the idea by some kind of observations and experiments.

When the explanation is a broad one, covering many facts or a large area, we usually call it a theory. If it is proved true, it may then be called a law or a principle. Thus we refer to Newton's theory of gravitation, or Newton's law of gravitation. Newton discovered this law of nature by first getting the idea, and then proving it through observations.

It is clear, then, that the idea, the hypothesis or theory with which the scientist starts, is a very important part of his whole work. Since it is not yet proved, where did he get it? Upon reflection, you will probably be able to answer that question for yourself.

Where did Newton get his idea for the law of gravitation, before he was able to prove it? There is a popular story that it came to him when an apple fell from a tree and hit him on the head. But even if this were true, think how many other apples must have fallen on how many other heads, producing only a little bump and no ideas whatever about a law of gravitation. How did it happen that Newton was moved to think up this particular idea?

How did it happen that Louis Pasteur and others thought of the germ theory of disease? Before it was proved true, it existed only as an hypothesis in their minds. Where did they get this hypothesis? In other words, how does any good scientist get a good idea?

There is another story, and this one is considered true, that Archimedes (Ar-kim-meed'-eez), a

noted Greek scientist of the ancient world, got a great idea when he was taking a bath. The King of Syracuse, according to report, suspected that a crown made for him was not pure gold. He feared the makers had defrauded him by using part silver and part gold. In those days there was no known way of testing such things, and the King did not wish to cut or melt the crown. So he handed over the problem to Archimedes, one of the best-known thinkers of the time, the third century B.C.

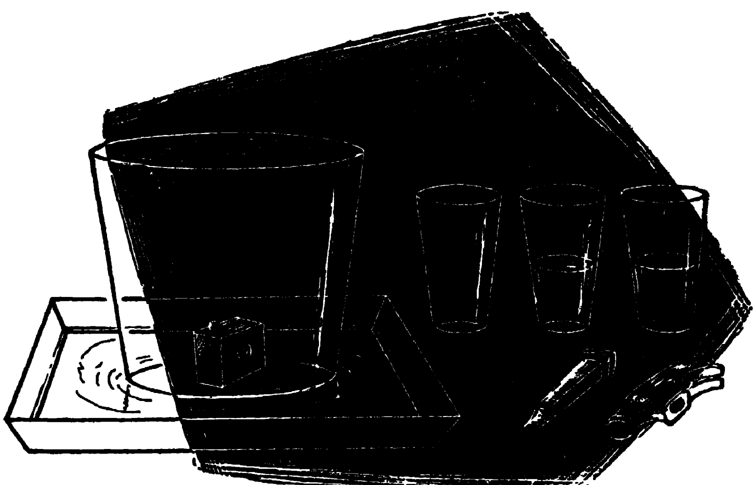
While taking a bath, Archimedes, like everybody else who ever took a bath, noticed that, as his body sank down in the tub, the level of the water rose accordingly. He began to think about this and to connect it with his problem. Do you see the possibility of any connection?

Archimedes reasoned in the following way: If the crown were put in the tub, the water would rise a certain amount, since any object sunk into water necessarily displaces the water from the space which it occupies. Now, he thought, if two objects were of exactly the same weight and were made of exactly the same substance, they would be of the same volume (size in cubic units). Hence, they should displace exactly the same amount of water, however different in shape they might be.

You can prove this for yourself by filling a glass or jar to the very top with water, so that anything put into it will make some water spill over. Now stand the filled glass or jar in an empty basin. Take any two or three solid objects made entirely of the

same substance, and of the same weight, but of different shapes. (Each one should, of course, be small enough to fit entirely within the glass.) Gently place the first in the water. A certain amount will spill over into the basin. Measure this amount by pouring the water from the basin into another glass. Repeat this procedure with the other objects, and you will see that the same amount of water is displaced.

Thus Archimedes had a basis for solving the king's problem. He weighed the crown and also measured how much water it displaced. Then he took some pure gold of the same weight as the crown and measured the water which it displaced. He showed it did not displace the same amount as the crown. Therefore the crown could not be pure gold.



Assuming that the other substance in the crown was silver, can you see how he then proceeded to discover the percentage of each in the crown? He took a piece of silver, weighing the same as the crown, and measured how much water it displaced. The amount was much greater than that displaced by the gold, for gold is denser than silver. That is, an equal weight of gold occupies a much smaller space.

Now Archimedes could compare the amount of water displaced by the equal weights of gold, of silver, and of the crown. He saw that the amount displaced by the crown was in between the other two, and thus calculated the proportion of silver that must have been used.

Far more important than solving King Hiero's problem was the fact that this line of reasoning led Archimedes to discoveries of lasting value for science. It laid the basis for the whole study of "specific gravity," which starts from the situation which Archimedes clarified: Equal weights of *different* substances which sink in water (or any fluid) displace *unequal* amounts of the fluid.

He proved that a non-floating object always displaces its own *volume* of water, that is, an amount of water equal in *size* to the object. He showed that a floating object, on the other hand, displaces its own *weight* of water. These are the ideas on which Archimedes pondered, we are told, as he watched the water rise and fall in his bathtub.

It is added in the story that when Archimedes thus obtained his solution, he was so overjoyed that he


shouted "Eureka!" (which is Greek for "I have found" something), and ran out without remembering the formality of putting his clothes on. While this would show that a great scientist is human, it still does not tell us where Archimedes' idea came from. For it is clear the king could have given any number of other people the same problem, and they might have taken baths all day and all night with no other result than keeping themselves good and clean.

Ideas do not spring out of nothing, though it may sometimes seem so. In truth, nothing comes out of nothing, which is natural enough. A person's ideas come out of his past experiences of one kind or another, and the way he reacts to them. Thus, the more knowledge and experience he has of a certain field, and the harder he thinks about what he already

knows, the better will be the new ideas he arrives at. The more he knows of the facts previously found by scientists, the less time he will waste on ideas that have already been proved false. Thus the fruitful hypotheses of men like Newton, Pasteur, Archimedes, Copernicus, Darwin, Einstein, or any other able scientist came out of their knowledge and experience. They came out of the fact that these men kept on turning over their problems in their minds to see what they might be connected with in one way or another.

There is a popular theory that great scientific discoveries come about by "accident." This may be true in a certain number of cases, but two things must be noticed. First, these "accidents" usually happen to those who are already prepared, by experience and knowledge of some kind, to notice them and appreciate their value. In other words, one must know something before one can even be aware of this kind of "accident."

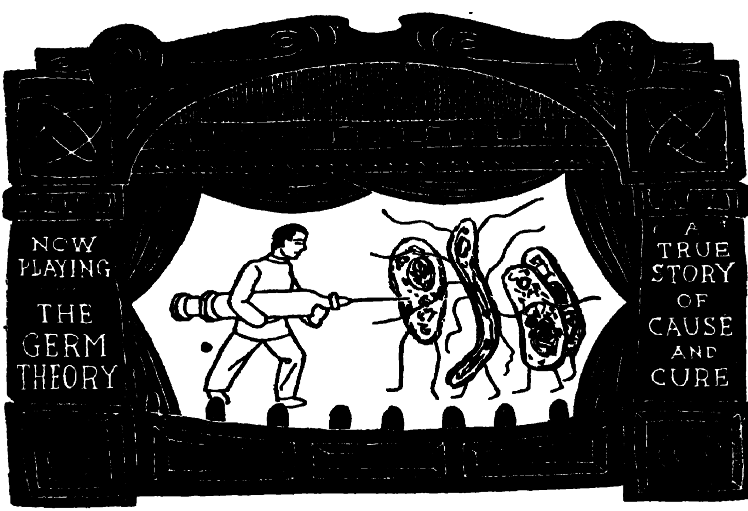
Second, there is always a lot of talk about something when it is *out of the ordinary*. When a man finds a thousand dollars in an old tin can on some empty lot, everyone talks about it and repeats the story for years. When a man earns a thousand dollars by steady work, it may never become a topic of conversation. But that doesn't mean you can rely on old tin cans if you really want to acquire a thousand dollars.

We cannot expect everyone to become a Copernicus or an Einstein. But anyone who gets interested in science or any other field, and who builds up knowl-

edge and experience in it, will find ideas coming to him quite naturally.

There is another point about theory which should be emphasized before we leave Step Two of scientific method. It is something that can be seen in the literal meaning of the word, which, like a good many others connected with the pursuit of knowledge, came into our language from the Greek. The word theory comes from an expression which means "to look at," and has the same root as the word "theater."

Just as a theater is a place where you can see a story unfolding on the stage, so a theory is something which enables you to see the explanation or meaning of a group of facts. It tells the logical story of those facts. Thus the germ theory of disease explains what was not known before: that a number of diseases have



the same kind of cause—germs. The theory of gravitation explains why all bodies move in space. The theory of evolution explains the facts of relationship between species.

It is interesting to notice that we can use the word theory in referring to such an explanation, even after the theory has been proved true. There is no actual contradiction in speaking of the germ theory of disease, for instance, even though it is now well proved. But when the word hypothesis is used, it always means a statement or theory as yet *unproved.* Today we would not speak of the idea that diseases can be caused by germs as an hypothesis.

Thus a scientific theory is not the opposite of a fact, nor is it a substitute for facts. Some people may use some theories that way, but they are not scientists. A theory is a general statement which in some way explains a group of facts, showing what they have in common, or indicating something important about them as a whole. Thus theory is absolutely necessary in science. As we have seen, until we have *explanations* of facts, there is no science.

## SHERLOCK HOLMES AND SCIENTIFIC DEDUCTION

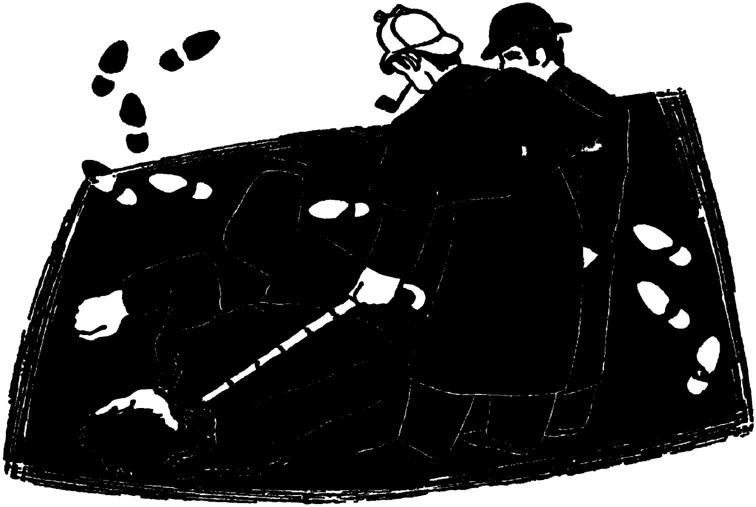
The third step in scientific method—making deductions from the hypothesis—brings us to the specialty of the great sleuth created by the English writer, Sir Arthur Conan Doyle. As anyone knows who has read the stories, Dr. Watson, the friend and admirer of this most remarkable of fictional detectives, is always amazed at the "powers of deduction" displayed by

the brilliant hero, who became the model for hundreds of others.

In their own way, all these detectives are indeed using the same basic process of deduction used in science, although, of course, in fiction they have the added advantage of an author who can always make everything turn out right. When Holmes carries out a quick inspection at the scene of the crime and then announces, "The murder was commited by a British sailor with a limp who just returned from China," what has he done besides astonish Watson, who made the very same inspection, and came out with no ideas at all?

We can easily picture Holmes explaining his reasoning in some such way as this: "You see these footprints? To you they may seem like nothing more than rather large footprints. But to the practiced eye, my dear Watson, they tell a story. Notice, if you will, the peculiar angle of the left print compared to the right, and the slight difference in shape. That is the print of a man who limps on his left foot.

"And this bit of ashes, half-smoked, is not from ordinary pipe tobacco. If you will compare its odor and appearance with thousands of samples I have in my collection, you will see it is from a cheap type of adulterated opium sold to British sailors in certain ports of China. Since it is fairly fresh, and there is no way to preserve this vile stuff, I would say he has but recently returned to this country. That he is an experienced seaman this knot around the victim's throat clearly shows, Watson. No landlubber would make it.



It is used almost exclusively in the merchant marine."

After all this, it is, of course, an easy matter to find the ship which recently returned from China, and to collar the opium-using sailor with the limp, who, of course, readily confesses.

Can you see where the deduction enters? Holmes reasons: If the murderer had a limp, it would account for this print. If the murderer were a sailor, it would account for this knot. If the murderer were a British sailor who had recently returned from China, it would account for these pipe ashes. Deduction, as we said, is a process of reasoning out what conclusions would follow if a certain statement were true. In each case, Holmes is reasoning that if the murderer were a certain kind of person, certain things would follow.

Now of course the whole point is this: Holmes is trying to think of just that kind of person who, if he were the murderer, would leave exactly the traces that were in fact left at the scene of the crime. In other words, he is trying to think of a theory or hypothesis which would exactly fit the facts he can observe.

Naturally, the more facts his hypothesis fits, the better it will probably turn out to be. He might merely say: "I observe footprints; therefore, my theory is that if they were made by the murderer in the usual way, then the murderer can walk." That would be a correct deduction, but it would certainly not be enough to narrow down the search to some particular suspect. In other words, that theory, even if true, would not solve the problem. A good theory must, of course, be such that, if and when proved true, it will solve the original problem.

By reasoning that all the facts he observes could be deduced from one assumption—that is, that they would all follow if it were true that the murderer was a particular sailor—Holmes has his theory. Now he makes the final deduction which becomes the acid test. If the murder was committed by a British sailor recently returned from China, who limps and smokes opium, then there should be some ship lately come from there, on which just such a British sailor will be found. It can then be seen whether actual fact bears out the deduction from the theory.

In some cases, deductive reasoning deals with absolute certainties, as in the following examples: If

this is a triangle, it must have three sides. If John has a sister Mary, Mary must have a brother John. If the man saw the post, he could not be blind. However, in science, as in detective work, we often have to deal with probabilities rather than certainties. Holmes can only say: If the murderer is a sailor, *it is probable* he would tie such a knot; if the murderer smokes this type of opium, *it is probable* he got it in China; and so on.

These are only probabilities, of course, because a sailor committing a murder might deliberately refrain from using a knot associated with his work, for fear of detection. Or, such a knot might be deliberately used by a non-sailor in an effort to throw the police off the track. And of course, the opium might have been bought by the murderer from someone else who had recently come from China. However, it is *more probable* he got it there himself, since it is a type sold for use rather than for smuggling or resale. And it becomes still more probable when we put that fact together with the fact that he tied a sailor's knot. In this type of reasoning it is often a matter of degree of probability; the more facts a theory explains, the truer it probably is.

Copernicus reasoned: If the earth were rotating from west to east, and revolving around the sun as a center, then all these apparent movements which we observe in the skies would be seen. Later astronomers reasoned: If the theories of Copernicus and Newton are correct, then a new planet should be detected at a certain position. Pasteur reasoned: If the souring of

milk is caused by bacteria, then the souring should not take place if bacteria are not allowed to come in contact with the milk. Archimedes reasoned: If the crown is pure gold, it will displace the same amount of water as pure gold weighing the same as the crown.

In these instances, the probability enters at a later stage than in the case of Holmes and the sailor. Holmes' premise, even if true, yields only a probability. That is, at the very start he can only say: if the murderer is this type of sailor, *it is probable* he did such and such. But the scientists can at least claim that if their premises were true a *certainty* would follow. They can say: if the rotation is of just this type, we *would* see just these motions. If the theory is correct in all respects, just this result *would have* to follow. This is true in each of the scientific instances mentioned. In them, we see the probability entering as the scientist goes on.

Take, for example, this reasoning of Copernicus: If the earth is rotating from west to east, at the same time revolving around the sun, then we should see such and such motions of the sun, stars, planets, and moon. We do see just such motions of those bodies. Therefore, he concludes, the earth is rotating from west to east, and revolving around the sun.

If you think it over carefully, you will realize that this kind of conclusion is not completely certain, unless we could prove that there was absolutely no other condition that could lead us to see just those motions that we do see. It is like saying, "If it rains, John

must stay home. I know he stayed home. Therefore, it must have rained." That conclusion is probable, but not certain, because there are other conditions that could make John stay home, such as illness or accident.

In the case of the earth, we have not yet been able to explore space very far beyond this planet; and it is at least possible, if not very probable, that other conditions might be causing us to see just those motions that we do see. Or, we might begin to see other motions that would change our ideas. The most Copernicus or any other astronomer could say is that this theory explains, better than any other, all that we have seen, and that it keeps on predicting more and more new things which turn out to be true.

What we are saying here applies also to the other instances of scientific reasoning we listed, and to most theories that are accepted in science. We can seldom claim to have complete and perfect truth. We are happy if we can gain a greater and greater degree of probability. After all, this is the only basis on which progress is possible. If we could claim complete and perfect truth in any field, progress would not be necessary.

### THE ACID TEST: EXPERIMENT

As we have seen many times in the course of our discussion, once a scientist has a problem, has formed an hypothesis, and has reasoned out by deduction what consequences would follow if his hypothesis were true, he must then find out by observation and ex-

periment if those consequences really exist. This procedure is what we have called the fourth step in scientific method: testing by experiment or observation the deductions made from the theory.

We have already dwelt a good deal on this very important part of the method of science. There is no need to expand upon it further at this point. However, we should add a word about terminology. The scientific method as a whole, which aims to establish general truths, is called "induction," or "inductive method." Deduction, or deductive method, which tells us what conclusions *would be* true *if* certain premises *were* true, thus is used as a part or step of scientific method.

The last step in our list, drawing the conclusion, follows, of course, directly from the preceding steps, and depends entirely upon them. While it contains nothing new in itself, emphasis ought to be placed upon the fact that it should never go beyond the evidence. Probabilities should not be mistaken for certainties. Nor should a conclusion true for a part or for a time be asserted as if it were true of the whole or forever. The real value of results is often lost when too great a claim is made for them. A genuine probability is better than a false "certainty."

CHAPTER

6

# Scientific Method and Social Problems

## ARISTOTLE IN NEW YORK

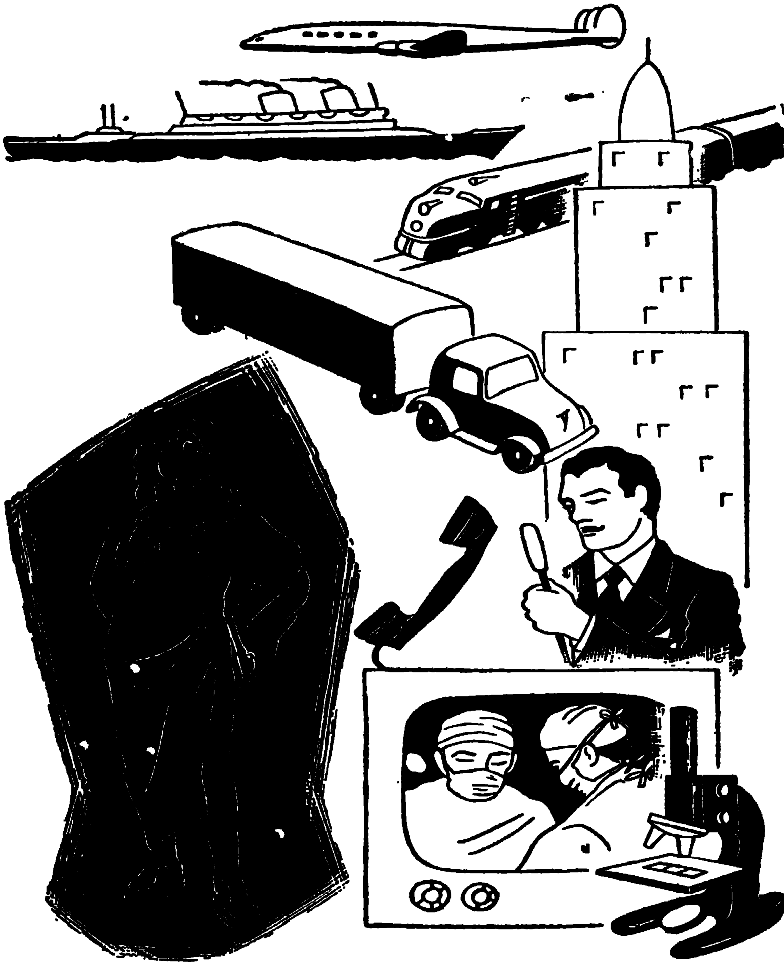
Giving your imagination free rein for a moment, suppose it were possible to bring back to life some great thinker of the ancient world—Aristotle, for example, who died in Greece in the year 322 B.C. It is safe to say that he would be greatly astonished, to put it mildly, by much that he would see. Brilliant mind that he was, he never dreamed that it would be possible for anyone to do hundreds of things we do every day with hardly a thought.

In fact, if he were first brought to a city like New York, he might even wonder, for a while, whether he had returned to the same planet. Think of the impression a busy airport, with its stream of big planes landing and taking off, would make upon him, who had never seen anything fly except birds and

insects. Leaving the airport by land, he would see automobiles, trucks, and long strings of railroad cars pulled by locomotives. Yet the only means of land travel or transport he had ever experienced were horses and other such animals, together with the chariots and carts they were trained to pull.

Not far from the airport he would see huge ocean liners capable of carrying thousands of people at a speed of 25 knots or more. Yet the best means he had ever known of traveling by water was a small sailboat or a galley rowed by many oars. The big ships in the harbor should particularly astonish him, since, in one of his books where he was discussing things that were impossible, he actually used as an instance "a ship a quarter of a mile long." Quite a few of the large ocean liners of today are near that length. He also wrote that the population of an independent state, under the best conditions, should not be more than a few ten thousands. He could therefore reflect that one or two of these liners would be big enough to transport an entire population of the size he considered natural.

Curiously enough, one of the reasons Aristotle gave why an ideal state should not have more people was that a greater number could not be successfully addressed at one time by a speaker. He wanted everyone to be able to witness and understand various public events, and he never thought there would be any means for them to hear and see what was going on except the natural power of voice, ear, and eye. What, then, would he think if he were told that through the



use of things called radio and television, hundreds of millions of people scattered over thousands of miles could see and hear the same speaker or performer at the same moment? We could hardly blame him if he began to be convinced that he had indeed been brought back to a different world.

In the world he had known, there was no better means of lighting a room than a simple oil lamp. No better way had been found to produce an edition of a book than laborious copying by hand. No mechanical refrigeration whatsoever was known. The existence of microscopic germs was not suspected, since the microscope was not to be invented for another two thousand years. There was comparatively little surgery, and no general anesthetic was known. It was considered quite natural for a large proportion of people to die at an early age.

In contrast to all this, Aristotle would see generators producing electricity capable of lighting a city at the flick of a switch. He would see telephones, telegraphs, and printing presses. In a modern hospital he would witness hour-long operations made possible by the use of anesthetics, and he would be able to look down the barrel of a microscope and see what no doctor in his day, or for two thousand years after his day, had ever seen—the germs which cause diseases.

All these things which would be so new and astonishing to Aristotle are, of course, the results of progress in what we call the physical or natural sciences. Such practical applications of our knowledge show how far it has gone beyond what was known to Aristotle in

these fields. He himself, one of the most productive scholars of the ancient world, wrote important works in almost every known branch of learning, including what we now call astronomy, physics, and biology.

## WHAT WOULD NOT BE NEW

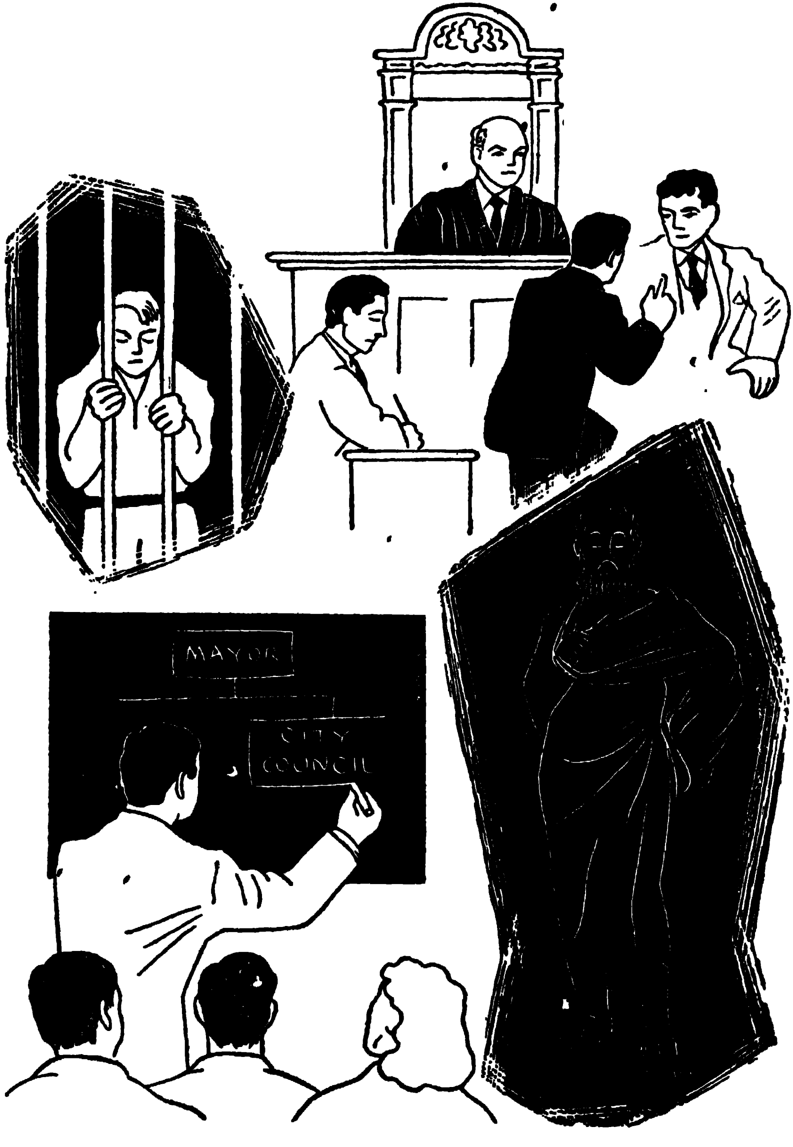
But the curious thing is this: While Aristotle would hardly be able to recognize the physical sciences and their applications as belonging to the same world he knew, he would have little difficulty in recognizing the social sciences and their applications. In most respects, what he would see in these fields would sufficiently resemble what he had seen and known in ancient times to assure him he was, after all, in the same world.

For example, what would he see in social fields like government, education, and law? If Aristotle were conducted downtown to the Municipal Building and City Hall, he might, before beginning his social observations, be shown the powerful dynamos generating electricity which lights the buildings and runs the elevators and other appliances. As concerns that, he would not have the slightest idea what he was looking at. He would immediately recognize, perhaps with a touch of pride, the Greek roots of the words "electricity" and "dynamo." But it would take considerable explanation before he would understand how the dynamos produced the electricity, how it was sent out to accomplish its effects and how the effects were accomplished.

Now suppose he were brought into the City Council to witness the processes of government. Would he recognize and understand what he was observing? There is no reason why he would not, in view of its similarity to what he had known and participated in himself in ancient Athens. There, too, legislators sat in council before the presiding officer, discussed and debated measures and resolutions, charged one another with corruption and incompetence, passed laws by majority vote, and engaged in all sorts of maneuvers behind the scenes. Aristotle would be able to teach the Councilmen fully as much as they could teach him.

Passing to the courts, he would no doubt be amazed and puzzled by the automatic elevator which, without apparent effort, would project him and a dozen other persons twenty stories skyward in fewer seconds. But once inside the courtroom, he would again feel himself at home. The accused up for judgment, the lawyers arguing the cases, the suits for damages, the criminal charges and countercharges, the judges handing down their verdicts—all this he had known, seen, and taken part in himself.

Suppose, after the conviction of some criminal, Aristotle were asked by a member of his escorting party: "What would you, Aristotle, now expect to happen to this man, on the basis of your experience?" Aristotle would undoubtedly reply: "I should now expect him to be brought to a prison, locked behind bars, and either be forced to remain there for a certain period of time, or be put to death." This was the procedure in


MAYOR
CITY COUNCIL

Aristotle's time, and, while there have been changes, its main features are still the same today.

Suppose, by the way, a similar question had been put to Aristotle during his visit to the hospital: "This patient has a bad case of appendicitis; that one is in the early stages of pneumonia; those children over there want us to make sure they will never get smallpox. What would you, Aristotle, expect would now be done to each on the basis of your experience?" Aristotle's reply would certainly be far from present practices, since he had never heard of vaccination, penicillin, or an operation for appendicitis. In many cases he probably would be inclined to say: "I don't see what can be done. I expect the patient will die." In no case would he have anything to teach the doctors in charge.

Having observed something of the workings of government and law, Aristotle might now be taken to a modern school or college. Would he have to be told what it was, or would he recognize it? There is certainly no reason why he would not recognize a classroom for what it is. Professors lecturing, students taking notes, pupils reciting, teachers correcting and marking—he had been through it all himself, both as student and as teacher. No doubt he could give to either much valuable advice. While our large-scale organization of education on a democratic basis, as well as some of our teaching methods, would be new to him, he would still be regarded as a competent teacher and an authority to be listened to.

Of course, in all those classes where the physical or natural sciences were being studied, Aristotle would have almost as much to learn as the pupils themselves (and much more to unlearn!). On the other hand, he could feel justly proud at seeing that in a modern university, many of his own works were still being used in such fields as political theory, ethics, and basic philosophy of life. In classes where these works of his were being studied, there could be no question whether Aristotle knew as much as the professor about the subject under discussion; rather, it would be the other way around.

Why is it that the works of Aristotle on physical science are never used as texts today, whereas some of his works in fields of social knowledge are still considered of first rate importance? Is it because he, as an individual, happened to know so much more about social problems, or had greater abilities and talents in those fields? It is hardly that, because Aristotle's works in all fields contain about the highest levels of knowledge reached in his day. He had great ability in almost every field he dealt with.

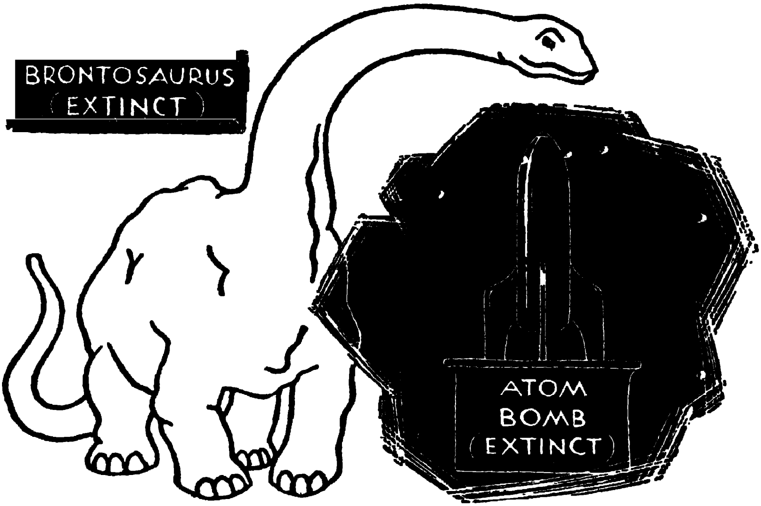
While we have certainly made some progress in all fields of knowledge since Aristotle's time, the plain fact is that we have made immensely more progress in the physical sciences than in social fields. How did we make it? We made it through the use of the method which we have summarized, in the way we have described.

THE GREAT QUESTION OF SOCIAL SCIENCE

Once that method had shown what it could really do, more and more thinkers began to raise the question: Can we apply the same method to social problems? And, if we can, will we be able to gain as much understanding, prediction, and control in fields like government, economics, and education as we have gained in physics, chemistry, and biology?

It is a fascinating question because, if we could ever attain as much control over social problems as we have already attained over medical problems, for example, we might no longer have to fear world wars, widespread poverty, or large-scale crime. Indeed, some would be inclined to put the question in a much sharper form: If we do not manage to attain enough social understanding, prediction, and control to prevent world wars, how are we going to have any future at all on this planet?

This question is particularly grave, of course, because of the recent development of atomic weapons, and their constant "improvement" in destructiveness. In this connection, it is curious to reflect that it was the very progress of the physical sciences that enabled us to harness the energy of the atom, and thus to produce the bomb. Now it may well be that further scientific progress, in social fields, will help to solve international problems peacefully. Then, perhaps, war can be eliminated as effectively as yellow fever, and atom bombs can be looked upon as histori-




cal monstrosities to be exhibited in museums, like the skeleton of a dinosaur or a saber-toothed tiger.

Of course, there is a *moral* problem involved here, too. Sometimes people who know how to do the right thing still won't do it. But knowledge always helps, and in many cases the right thing is not done because there is not sufficient knowledge of *how* the right thing *could* be done. While there is no substitute for good will and good intentions, science can strengthen them and open up more effective ways of putting them into practice.

### COMTE, THE PIONEER

In the middle of the nineteenth century, scarcely a hundred years ago, the first attempt was made to organize a full-scale science to deal with the whole field of social problems. This was done by a French-

man, Auguste Comte, who used a new word, sociology, meaning the science of society, as a name for the new field.

Of course, as we have seen in our preceding discussion, there had been attempts to build up social knowledge ever since ancient times. Man is a social animal; he could not get along, even in the simplest communities, without some kind of knowledge and rules to help him meet the various problems which arise in group living.

But all these attempts suffered from one of two weaknesses, and sometimes from both. Many of them dealt only with some one particular problem, such as trade or taxation, without seeking or finding general laws which would explain the connection of those matters with other social matters. And, worst of all, most of these attempts, whether they dealt with a single problem or a broad area of society, did not seek or find the kind of knowledge which added greatly to our ability to predict and control.

Comte wanted that particular kind of knowledge about society, the kind we call scientific. Living in the nineteenth century, he could already see the remarkable—indeed, almost miraculous—results which that kind of knowledge was capable of producing. In fact, Comte had the idea that a genuine science of society could not have been developed earlier, because it had to build upon preceding sciences like biology and physics, and these sciences had not come of age, until close to his day.

In any case, the great aim, as Comte saw it, was to seek and find the kind of knowledge about social problems that would enable us to discover general laws that were basic, and thus increase our powers of prediction and control. Then, he believed, we would be able to build up the separate social sciences, such as government, economics, and education, on really solid foundations.

The brilliant progress of the physical sciences combined with the growing seriousness of man's social problems presented an immense challenge to a thinking mind. Comte made it his life work to try to meet that challenge. It still faces us, for, even if Comte had succeeded in all he tried to undertake, it would have been but a beginning. Moreover, though Comte is certainly deserving of great credit as the "father of sociology," it must also be said that not all of his work has stood the test of time.

In one sense, however, the most important thing was not the detailed work Comte did, but his basic idea—the idea of a genuine science of society. And he was not alone in holding that idea. Many another thinker, before and since, has been inspired by it, though few have worked on it in so organized and systematic a way as Comte.

### HOW FAR DOES SCIENTIFIC METHOD APPLY?

Let us try to state what this idea means in terms of scientific method. We might begin by asking this question: Is there any impossibility about applying to social

problems the different steps of scientific method which we discussed in the preceding chapter?

There would certainly be no dispute about the first step. Everyone would agree that we have plenty of social problems which we can express as definite problems. For example: How can we prevent wars? What are the causes of different types of crime? How can steady employment best be maintained for all? Many other social problems could, of course, be mentioned, some more specific and some more general than these.

How about the second step of scientific method, the formation of hypotheses? Again, it would be generally agreed that any number of hypotheses could be formed about any number of social problems. Of course, the final test is whether or not they will be successful, but there is nothing which makes it impossible to apply and use this part of the method in social fields.

What of the third step—making deductions from the hypothesis? This, of course, is also entirely possible. If the problem is real, and the hypothesis deals with actual facts that can be checked in some way, it will not be difficult to deduce from it various consequences which ought to be true if the hypothesis is true.

Let us take the example of crime. Suppose our problem is to find the major cause of crimes. Our hypothesis might be that the major cause is poverty. Naturally, this is only one of a number of possible hypotheses that might be chosen. But, supposing your own knowledge and experience (as a social scien-

tist, of course, not as a criminal!) has led you to choose this as the most likely idea. What would you deduce from it?

Reasoning out what ought to follow if it is true that poverty is the cause of most crimes, you would certainly make these or similar deductions:

1. If poverty is the main cause of crime, then it ought to be true that most crimes have been committed by individuals who were very poor.

2. If poverty is the main cause of crime, then it ought to be true that in countries, states, or cities where there is more crime, there is also more poverty.

3. If poverty is the main cause of crime, then it ought to be true that in periods when crime is on the increase, poverty is also on the increase.

4. If poverty is the main cause of crime, then it ought to follow that if we took all the people who tend to engage in criminal activities, and saw to it that they obtained whatever was necessary to make a good living by honest means, we would thereby prevent most crimes from happening.

In these deductions, we are dealing, for the sake of simplicity, with the single factor of poverty. Of course, in any complex matter, one single factor is never the whole cause, although we sometimes talk as if it were, as when we say a certain microbe is the cause of a certain disease. What we really mean is, it is a necessary part of the cause. Where the disease is found the microbe is found. But it does not always follow that where the microbe is found the disease is found. The other factors must be present, too. In disease, these

other factors are usually types of weakened bodily conditions. Thus one person may "fight off" a disease, even though exposed to the microbes, while another falls sick. . . .

If we were actually working with the hypothesis that poverty is the cause of most crimes, we would, of course, take it for granted that other factors are necessary, in addition to poverty—*moral* weaknesses, emotional abnormalities, or the like. For it is quite clear from the start that not everyone who is poor is a criminal. Yet this would have to be the case if the hypothesis meant that poverty by itself was sufficient to cause crime. In other words, in making our deductions as listed, it is assumed we have taken account of the other factors, whatever they are, which must accompany poverty.

These are only a few of the deductions that could be made from that particular hypothesis. Suppose, by the way, that someone at this point were to raise a question: How do we know we have made these deductions correctly? The answer is, of course, that logic alone tells us. So far, it is entirely a matter of *reasoning*. Reason tells us that *if* poverty is the main cause of crime, then it *would* be true that most of those who committed crimes would be poor, and that the other consequences deduced would also be true.

This is the same process of reasoning we use when we say: If I were a bird, I might be able to fly. Of course, people sometimes make mistakes in reasoning. Even when it is as brief and simple as our instances in this case, it is possible to get mixed up. And when the

reasoning is long and complex, it is still more possible. But the point is that in this third step of scientific method, we are not yet examining *facts*. We are deducing by reason what facts can and must be found *if* the hypothesis is true.

Our next step, naturally, is to make observations and experiments to see whether these particular facts can be found. Is this step possible in social fields? There would be little dispute about observation. Numerous observations can certainly be made, and are made every day. All kinds of records and statistics can be and are kept. For example, many facts are already on record, or can be found, about crime. However, it is clear that the possibilities of *experimenting* are far more limited in the social than in the physical sciences.

In physics and chemistry we can experiment to our heart's content with elements and compounds, atoms and molecules, weights and motions, without meeting many difficulties. So long as we do not damage people or property, we can do as we please with the elements and compounds, atoms, molecules, and so on. But, of course, we cannot be quite so free with human beings and social institutions, which are the subject matter of our social problems.

However, we must not think that experimentation is impossible in social problems. In recent years a type of large-scale experiment has grown more frequent: Certain measures, such as new school regulations or taxation procedures, are introduced into certain communities. At the same time, the experimenters also

observe other communities, as similar as possible to the first group, but in which the new measures will not be introduced. You probably can see the reasoning behind this procedure: The new effects caused by the new measures can be more easily seen and judged by comparing what does happen and *does not* happen in the two groups of communities.

Suppose, for example, you wish to find out whether a certain program of neighborhood activities will cut down juvenile delinquency. Government or private agencies may be willing to finance the program on a large state or national scale only if they are convinced it will bring results. In this case, you might well use the strategy just described.

Introduce the new program in one or two neighborhoods. Select a number of neighborhoods similar to these in as many ways as possible, particularly as regards juvenile delinquency. But do not introduce the new program in them. Thus, both groups of neighborhoods, before our experiment, had about the same rate of juvenile delinquency. Let us call it 100. Now suppose, after the new program is introduced into the first group of neighborhoods, the rate of juvenile delinquency drops to 30 or some such low figure. If the rate remains at or around 100 in the other group, there is a high probability that your program is really effective.

It is clear that this reasoning depends on several conditions:

1. The degree of similarity in the neighborhoods, especially in the characteristics of the people. Only to

the extent that the people in both communities respond in about the same way to the same things can the method of this experiment be used. For example, if you wished to include in your program folk dance competitions for which there was enthusiastic interest in one group of neighborhoods, but in which the other group had no interest at all, we would not have a fair test.

2. We must also make sure that the new program is the *only* change taking place in the first group, and that *no change* of any kind affecting juvenile delinquency is taking place in the second group. (Otherwise, we might not be sure whether the results obtained are due to our program or to something else.) It is often difficult to be certain of such things in large social groups, whereas in laboratory experiment


this is fairly easy. If we wish to test the effect of a chemical on plastic or a microbe on rats, we can more easily control the situation to see that the new thing is the *only* thing that is different. Then, if there is a new result, we can be certain of its cause.

We usually refer to the group or case which is not brought into contact with the new thing as the "control," because it affords a basis of comparison with the experimental group or case in which the new factor has been introduced. A project which tests out something in this way is often called a "pilot" project, because it shows the way for larger efforts to come. Organizations like UNESCO (United Nations Educational Scientific and Cultural Organization) have launched several pilot projects for problems, such as overcoming illiteracy, in different parts of the

world. When we reflect that a majority of the human race has never yet learned to read and write, we realize how important such projects are.

Many types of experimentation along these lines are possible, and have been carried out. An interesting experiment combining both physical and social science was recently carried out in several places. The aim was to see whether a certain chemical, introduced into the water supply of a city over a considerable period of time would cut down the rate of tooth decay, especially among children. New experiments in social fields are constantly being undertaken in business, government, and community activities.

At the same time we must remember that a high degree of scientific progress can sometimes be made on the basis of observation alone. Even among physical sciences, a field like astronomy owes most of its results to observation rather than experiment. We cannot do much *with* or *to* stars and planets, but we can watch them carefully. You may also have noticed that in our example about poverty and crime, the first three deductions from the hypothesis could be checked by observation alone. Experiment would be necessary only for the fourth deduction.

The final step of scientific method, drawing the conclusion, is, therefore, something that can be done on the basis of either observation, or experiment, or both. It is clear also that it can be done in social as well as physical science, though not always with the same effectiveness—at least, as yet.

Where there is a will, there is a way. The attempt

to put social knowledge on a scientific basis is something comparatively new. During the last hundred years a good deal has been done; and, without doubt, more and more will be done as time goes on.

The scientist feels sure that wherever things can be observed to happen, causes and laws of some kind are at work bringing them about. And if the laws and causes are there, he sees no reason to believe it is impossible to discover them. At any rate, he is determined to try, and to keep on trying. It is a great adventure, and it has great rewards.

CHAPTER

7

# Arts and Sciences—Creative Partners

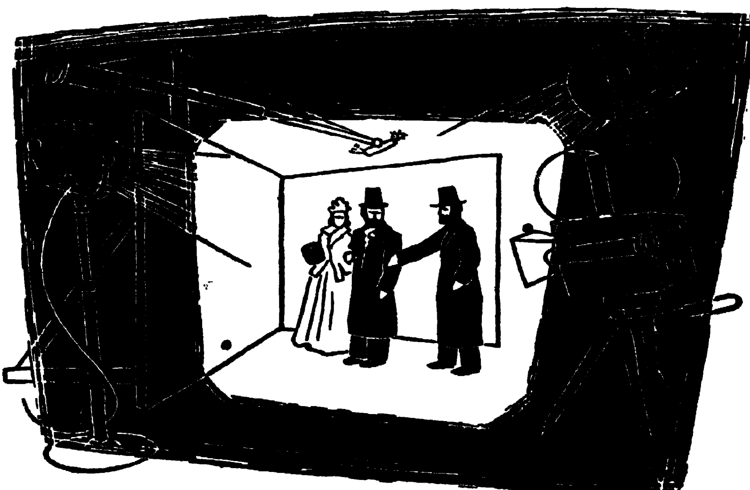
## HOW SCIENCE HELPS ART

In the first chapter of this book we pointed out that one of the reasons why science is studied is to enjoy the world more. It must not be forgotten that understanding something increases the possibilities of enjoying it; and that is one of the links connecting science and art. For art also is, among other things, a way of enjoying the world. There is no antagonism between these forms of enjoyment. In fact, they cooperate with and supplement each other in many different ways.

Take for example any good stage play or motion picture which holds the audience's interest. Millions of people all over the world may sit for hours, entranced by the effect it creates as it unfolds before them. Does not this effect depend on a close co-

operation of art and science? Not only must the author create characters, tell a story, and bring out moods. There must be scenery and background, lighting and camera effects, projection and sound effects—a thousand and one "technical" devices to make the characters live, the story real and the moods convincing.

All these technical effects are, of course, the practical applications of scientific knowledge—from the design and construction of the walls, ceiling, and seating arrangements of the theater itself, so that all can hear and see as distinctly as possible, to the latest type of color film or telescopic camera lens. In fact, the very origin of motion pictures was partly dependent



on scientific invention. The "screen," which has come to play such a large part in the life of the world, is thus a result of the co-operation of science and art. Our enjoyment of what it presents owes an equal debt to each.

Unfortunately, not everything on the screen is of high quality. But when it does a good job, it is not only a means of pleasurable relaxation, emotional enrichment, adventure, and thrill. It is also one of the most effective and widespread means of communication between different nations that the world has ever seen.

For the screen not only overcomes the barriers of space and time which separate nations and peoples from one another; it also overcomes the barriers of language. When millions on one side of the earth can see how millions live on the other side of the earth, they can better understand one another's problems. When they know they laugh at the same things, and cry at the same things, they have a bond which makes them feel less strange and alien to one another.

Sharing things is a big step in getting acquainted, and the world today shares the movies. In this, the film is like music, which also speaks a language everyone understands. In cities all over the world, wherever you may travel, you will find many people acquainted with two products of present-day American culture: Hollywood movies and our popular music.

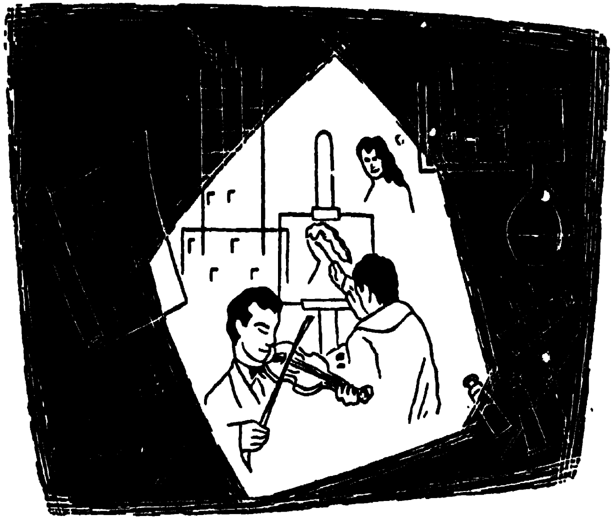
One could certainly wish that what they sometimes see and hear in this way gave a better account of us to

the world. We may hope for improvement in that, as time goes on, and as more attention is given to these matters. In any case, it is very important to have products of art and science which can create bonds of enjoyment and understanding between people, no matter how far apart they may be in space, time, or language.

In radio, television, and recording we find combinations of art and science with similar values. Music, entertainment and public affairs which, a generation or two ago, were experienced only by a small minority of wealthy people, are now available to the vast majority in any country where industry is well developed. Thus the progress of science creates greater and greater possibilities of enjoying the arts, and at the same time creates new art forms to enjoy.

However, it is not only in recent times that the co-operation of art and science has been so fruitful. When we stop to think of it, almost every art, however old, depends upon one form or another of that co-operation.

In most kinds of music, except vocal, a great deal depends on the careful construction of a complex musical instrument. The making of a fine violin or piano in itself represents a combination of applied science and artistic craftsmanship. An art like painting owes a great deal to the scientific processes by which oil and water colors are produced. And architecture would exist only on paper were there no knowledge of mechanics, building, and engineering.



SCIENCE AND THE ENJOYMENT OF BEAUTY

The way in which science has aided the production and use of art forms is only one kind of co-operation in these fields. There are others equally valuable. As we said before, it is a fact that scientific understanding adds to our enjoyment of beautiful things and, in many cases, cannot be separated from it.

For example, suppose a person knew nothing of the truth about the stars and planets. Could he be expected to appreciate to the full their beauty and majesty? On a clear night probably everyone who steps out of doors feels impelled to gaze overhead at the countless points of light glittering in the heavens. No doubt this was just as true of primitive man tens of thousands of years ago, as it is of us today. Even

some of the animals seem fascinated by what they see in the night skies, and have their own way of reacting to it.

But modern man alone *knows* how truly vast is space, how truly huge are those flaming masses, how truly numberless they are, and how truly great are the possibilities of other bodies and forms of life moving along with them. Does not this very knowledge help to make us feel their splendor? In fact, how would we be able to appreciate their true magnificence without such knowledge? Without an understanding of the facts, we might think all we were looking at was a number of small and pretty lights a short distance away. Thus we would be missing the real show altogether. Or, if we were victims of superstition, we might be filled with a sense of terror instead of a sense of limitless, majestic beauty.

The same applies to our enjoyment of the ocean, or of the woods and fields. Everyone who comes suddenly upon a view of an immense body of water extending farther than the eye can reach and deeper than it can fathom, is held in awe-struck admiration, just as the sight of a full moon making a shining path of rippled silver stretching far out to sea holds people spellbound. When these people know something of the many forms of life, both plant and animal, that inhabit the ocean, do they not have a richer appreciation of its grandeur? If they know not only that the moon's soft light reaches the surface of the waters, but that its powerful gravitational force is

pulling the tides that move through their depths, will that fact not add to the fascination and enrich the interest of the scene?

### CREATIVE IMAGINATION IN ART AND SCIENCE

In some ways the most interesting link be[t]
science and art is what goes on in the minds of the artists and scientists who bring them into being. This link is creative imagination, which plays a large part in the work of the scientist as well as in that of the artist. At first sight, it may seem strange to associate imagination with scientific work. That is probably because the word imagination is usually identified with "make-believe." However, it goes much deeper than that.

Imagination is not only a means of dealing with the *unreal*. It is also a means of dealing with the *unknown*. The creative imagination of the scientist plays a great part in helping to make the unknown known. The way in which this takes place has many similarities to the work of the artist. To see these, let us recall something of how the artist works.

It should be remembered that the artist is by no means interested exclusively in the unreal. When he makes believe, it is seldom just for the sake of "make-believe." A good artist, whether he is a painter of pictures, a writer of stories or poems, a composer of music, a maker of statues, a designer of buildings or any number of other things, is usually interested in some part of the real world. He wants to convey to other people something he has learned or felt about

some aspect of human life as he knows it. When he uses "make-believe," it is mostly as a means of bringing home his point, of telling to others what he wants them to know or feel.

Even when the artist's only purpose is to entertain, that, too, is a purpose, something he wants to do in relation to the real people of the real world. However, as we all know from reading stories or poems, seeing plays, listening to music, looking at pictures, statues, or buildings, artists have many purposes.

Sometimes they want to convey certain emotions which they have experienced. Or, they may want to reveal some tragic possibility of life which has moved them, or to depict scenes and characters which, to them, help make life worth living. Sometimes they want to show how combinations of colors, lines, shapes, and masses can bring out effects which are dramatic, suggestive, spectacular, or graceful. Whatever their purposes, artists try to convey what they want to convey in a way that will enjoyably hold our interest.

A good artist does not work on just any subject. To the novelist, not all stories are equally worth telling; nor does the painter feel that all scenes or persons are equally worth painting. Different artists have different ideas about what is worth working on, but all have *some* idea. In other words, a subject is not selected unless the artist feels it has importance or significance of some kind.

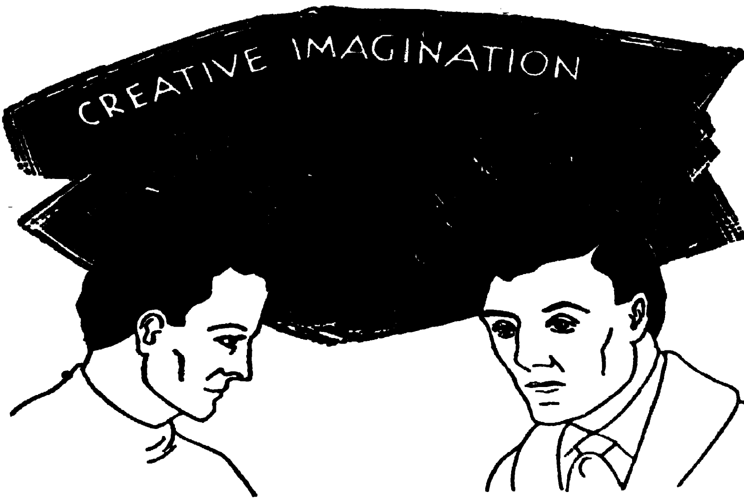
In thus selecting a subject, is not the artist doing something quite similar to what the scientist does when he selects a problem? If neither one is imitating,

copying, or merely taking directions from someone else, then both are certainly performing a creative act at the very start. Each one visualizes the possibility of a new bridge between that which now exists and that which does not yet exist. Each one is convinced that this bridge, the solved problem or the finished art, will add something of value to what now exists.

When we come to the question of how the bridge is to be built, it is even plainer that the methods of the scientist and the artist are similar (although not exactly the same). The scientist's ideas of how the bridge might be built are, of course, his hypothesis together with his plans for observations and experiments to prove it. For, as we have seen, after he has a problem, he must arrive at some idea of how that problem might be solved. Just so, the artist must arrive at some idea of how he is going to treat his subject, so as to accomplish the purpose and achieve the effects he has in mind.

In other words, each must try to put what he already knows into some new combination. In this way, he tries to figure out how to do something that has not yet been done. What is needed for such a task is creative imagination. Without it, no one can be either a good scientist or a good artist.

Of course, there are many differences between the scientist's work and the artist's. For example, the way in which each tests his ideas and results to see whether they are satisfactory is not the same. The artist pays far more attention than the scientist to the question of how his work affects the feelings and emotions of




his audience. If a story, a picture, or a piece of music does not arouse and hold our interest, we usually say it has failed as a work of art, even though it may contain a good idea or a great truth of some kind.

A scientist's work is not judged in that way. If he has good ideas and finds some truth which increases our ability to explain, predict, and control, he is usually regarded as successful. Yet the way in which he presents his results may be quite lacking in stylistic effectiveness or dramatic power.

However, this certainly does not mean that a man is a *better* scientist if he presents his results in a dull and uninteresting way. Quite the contrary is true. A scientist wants to explain things; and the more effectively he presents his results, the quicker and better he will be understood. When he is understood, he will

naturally have a better chance to obtain further opportunities or facilities which he may need for more scientific work.

We might also mention, in passing, that an artist would not be considered a better artist because his work contained a great deal that was untrue in a scientific sense. Untruth in itself is certainly not preferable to truth. Of course, it is a different matter if the untruth is in the form of deliberate "make-believe" which everyone recognizes as such, and which serves a purpose. In that case, the purpose itself usually goes back to something that is real, and is connected with truth. An artist can often become a better artist if he knows the scientific truth about whatever he is dealing with. And a scientist can often become a better scientist if he knows how to present the truth in an effective and interesting way, so as to bring out its full meaning.

In view of these facts, it is not surprising to find people who are equally devoted to art and science, who are interested in and enjoy them both. We can even find men of first-rate talent in both fields at once, such as the great Italian painter and scientist of the Renaissance, Leonardo da Vinci (Vin′-chee), and the ancient Roman poet, Lucretius (Loo-kree′-shuss), who presented in his poetry some of the most advanced scientific thought of his times.

Lucretius wrote almost two thousand years before our American poet, Walt Whitman. Yet he was carrying out, for his own day, a thought which Whitman expressed in his *Democratic Vistas* when he said:

"America demands a poetry that is bold, modern, and all-surrounding and cosmical, as she is herself. It must in no respect ignore science or the modern, but inspire itself with science and the modern."

Of course, people's tastes differ, and no one likes everything equally well. However, it is important to bear in mind that there is no reason whatever to believe that if you are interested in and enjoy art, you cannot be interested in and enjoy science; or that if you like science you must then dislike art. Art and science are not antagonists, but partners. Working together, they accomplish some of the greatest things that are within the power of man.

CHAPTER

# 8

# The Future Of Science

## SCIENCE FICTION AND SCIENCE FACT

Science is the sort of thing that can always look forward to progress, even though it once slowed down for a thousand years. The reason is that the roots from which it grows—the ability to observe, manipulate, and think—are part of man's nature. And the soil in which it grows—the need for understanding, prediction, and control—is limitless. There will always be more to know and to do; and, unless something tragic should happen to the human race, people will always come forward, sooner or later, with courage and ability enough to meet the challenge.

Nowadays we witness an ever-increasing flood of what is known as "science fiction." Indeed, there has always been a certain amount of this sort of thing, from the earliest times. When we read folk tales, stories, and legends, some of which are so old we

hardly know when they began; we can clearly see the desire to conquer time and space, and to lighten human labor. We see the human imagination leaping ahead to the possibility of breath-taking triumphs over monsters which threaten people.

The seven-league boots, the cape that made its wearer invisible, the flying carpet, Aladdin's lamp, the magic beans that grew a stalk into the clouds—are these not the remote ancestors of Superman with his bullet-proof body hurtling through the air, of the space ships and space men, of the mechanical monster with the electronic brain, of the invisible man?

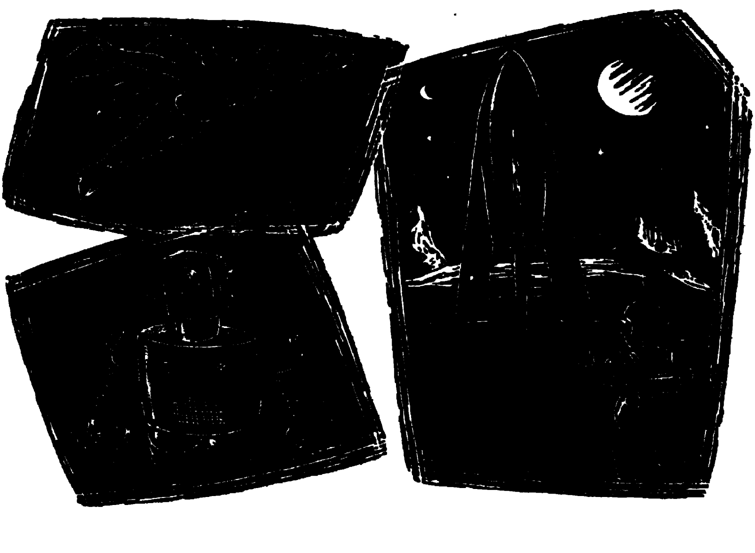
How many stories there are, which for thousands of years were nothing but fairy tales, of man flying through the air on magic carpets, magic horses, with wings of wax, and in all sorts of other ways! And how curious it is to reflect that man not only did learn to fly, but that the way in which he did it made most of the imaginary methods seem rather poor. How could a mere magic carpet compete with the comforts, speed, convenience, and roominess of transoceanic sky cruisers and the latest jet liners?

It is not only in folk tales and fairy stories that men of old expressed their hopes and dreams of overcoming the obstacles of time, space, and natural forces. The serious literature of scientific imagination is also very old. For example, Empedocles (Em-ped'-o-kleez), a noted thinker of ancient Greece, who lived 2,400 years ago, forecast the possibility of controlling the winds and the weather, and even of reviving the dead.

While this type of literature sometimes becomes associated with harmful forms of sensationalism and commercialism, it is, when well done, a source of strength and inspiration. It dramatizes the desire for and belief in scientific progress, and that is something which is very valuable. What should be kept in mind, of course, although unfortunately it is seldom brought out, is that upon which the progress of science depends: the method we have been discussing. There is nothing wrong with enthusiasm, adventure, and excitement in themselves; and the progress of science owes something to them. But, of course, they must be joined to a method that is capable of bearing fruit. Otherwise, they will be barren, perhaps also misleading and detrimental. While there can be plenty of adventure in science, we must not forget that there is also plenty of hard work, some of it

quite unexciting in itself. Like any other complex and enjoyable activity, science requires patience and practice to be learned.

The really remarkable thing, as we look back over history, is the fact that the actual progress of science has put so many of these flights of fancy in the shade. Not only do we find numerous instances, such as the airplane, telephone, and submarine, where the actual accomplishment, when it came about, was far more powerful and efficient than the purely imaginary construction. We can also find plenty of cases, such as radio and television, where apparently even the strongest imaginations were unequal to the task



of thinking up such possibilities until shortly before they were realities.

### NEW WORLDS TO CONQUER

A good deal of the science fiction of today is concerned with the exploration of space, interplanetary travel, and the like. While of course, nothing of this kind has yet been done in fact, the judgment of many responsible scientists for some time past has been that the actual progress of science is bringing us closer and closer to that point. More and more serious work is being done on means and methods of flight to other bodies, such as the moon and nearby planets.

There can be little doubt that one of the great areas of future progress in physical science will be in that direction. Indeed, it may be said that the progress we have already made in only fifty years, from the complete absence of any power-driven flying machine to the best planes of today, is greater than the progress we need to make from today on in order to reach the moon. Today, such a goal might be regarded as a matter of degree. Its attainment depends upon improving a method which already exists, while the original development of a workable flying machine was a far more radical step, something quite new.

In the process of trying to reach the goal of interplanetary exploration and travel, people will undoubtedly be exposed to many a danger, adventure, and thrill the like of which no human being ever experienced before. Truly, what they will meet with no one can say, except that, as in earlier instances, the

reality will probably be far more wonderful and valuable than the creators of fiction are able to imagine.

If we were considering possibilities of the far distant future, we would have to take account of the fact that our sun, with its nine principal planets that we are aware of, and the moons following some of them form only one planetary system. Our sun is a star; and so far as we know, many stars may have families of planets and moons. Because planets and satellites are so much smaller than stars, we have not yet been able to find out the actual situation. Astronomers estimate that there are hundreds of billions of stars; thus, planets may be very numerous. Since a great variety of life forms exist on the planet earth, the question has often been raised whether life may not be found on other planets.

Among the planets revolving around our own sun there is one, Mars, which seems to have natural conditions for maintaining some forms of life as we know them, particularly plant life. But when we consider what might exist among the numerous planets which may be following other stars, there is room for many, many further possibilities.

If the discovery and exploration of continents like North and South America on our own planet opened up such great possibilities for mankind that we speak of the New World, what may the discovery and exploration of other planets mean? The answer to such a question may well be beyond even the most powerful imagination today.

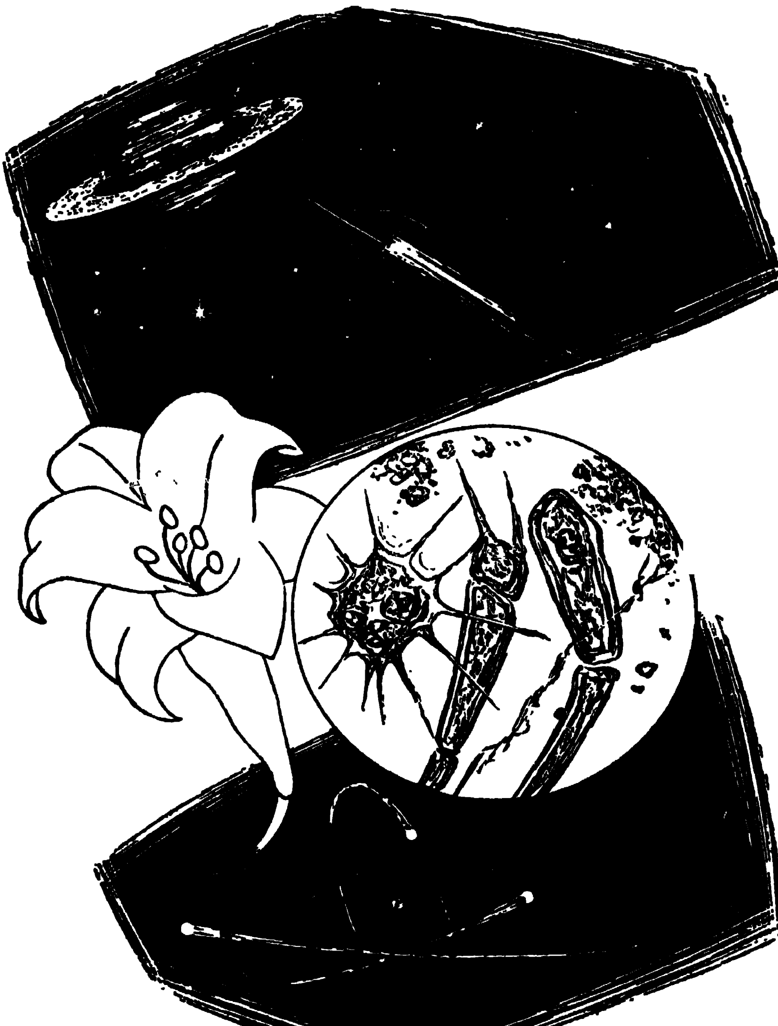
FROM ATOM TO STAR

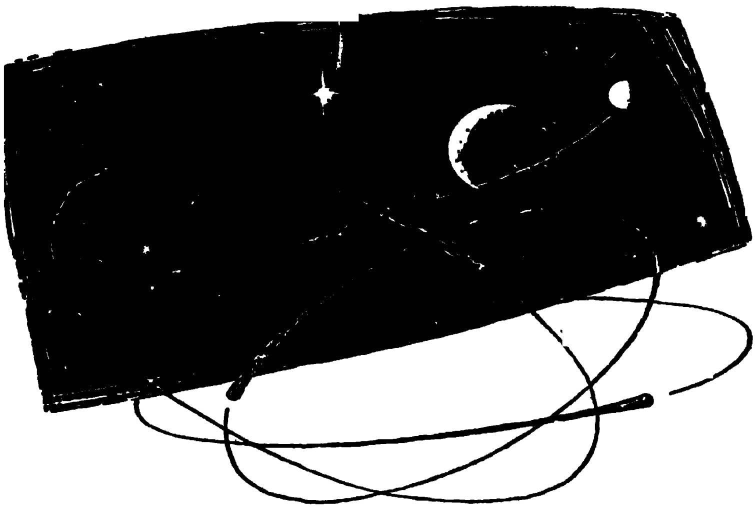
It is not only in the skies that there are new worlds to conquer. In a drop of water, in the smallest seed, in a single living cell, in organisms so minute that they can be seen only under a microsope, and, indeed, in things so tiny they cannot even be seen under the most powerful microscope yet built—in the atoms themselves—many a new world is waiting to be conquered.

In these small but very complex structures are the forces which accomplish the results that have always been seen—growth, health, disease, motion, vegetation, decay, weather, chains of mountains, clusters of stars. But only now are we beginning to understand them. We have been observing these things with the instruments and methods of modern science for less than a hundred years. Hence, this whole story is only just beginning.

We do not usually stop to think that a discovery so basic as the germ theory of disease is less than a lifetime old. Many people alive today were actually born before it was established. Great progress resulted, but some of the greatest victories of medical science are still to be won. Many a deadly disease still remains unconquered. In every science, many a key problem still remains unsolved.

Even at these early stages, a curious fact has emerged: The smallest units of matter, the atom and its parts, seem to be organized in a way which sug-





gests a degree of resemblance to the way in which the largest units, the stars, are organized. Certain electrons within the atom appear to whirl around the nucleus at its center somewhat as our planets circle the sun. Scientists do not yet know enough about such resemblances to draw many conclusions. But all are agreed that one of the most important achievements of modern science was the discovery, just a few years ago, of a method of releasing the immense energy stored up in these tiny atoms.

This discovery meant two things: First, it was the experimental proof that the basis of the modern theory of the atom is correct. That is, this particle of matter, so small that we have so far seen not it, but only its effects, really is a storehouse of almost un-

believably powerful energies. Ability to predict and control was thereby increased on a large scale in various directions.

Second, this very energy, taken from the *tiniest* units of matter known, makes it possible for us to think of exploring the *largest* units of matter known. The idea of constructing some form of aircraft capable of covering the immense distances between our earth and other astronomical bodies received great encouragement when a way was found to split the atom and release its energy. Why? Because this discovery presented a possible solution to a problem that had baffled every creator of imaginary space ships: how to have a tremendous quantity of power or fuel stored up and ready for use in a small container.

In all these fields, far and near, large and small, there is room not only for the greatest progress in the known sciences; there is plenty of room for the creation of *new* sciences. There is no reason to suppose that the number of sciences will remain forever what it now is. Only, of course, the dangers of "waterology" must be avoided. New sciences that are genuine, and accepted as such, will not be mere collections of truths. They will be collections of those particular truths which solve problems and explain things in such a way as to give us new powers of understanding, prediction, control.

### SOCIETY, SCIENCE, AND YOU

And, certainly it is not only in fields of physical science that there is room and need for progress. In

social fields there is, if anything, even more room and need, not only for progress in the known branches of knowledge, but also for new sciences. This need could hardly be exaggerated. As we have remarked several times before, the very progress of physical science, which resulted in the construction of atomic bombs, has placed before us the following social problem: We must either find a way to adjust international relations peacefully, or we may destroy civilization and possibly the human race along with it.

On the other hand, it is equally clear that if world wars can be prevented, and all the new possibilities are used for peaceful progress, a new age may well dawn. Atomic energy applied to industry, medical research increasing by leaps and bounds, new scientific fields opening up—all this could indeed bring us benefits we can hardly imagine. But in order to take advantage of such possibilities, we must solve our social problems.

In a sense, it is not surprising that our social knowledge is still at an early stage of scientific development. As we noted before, less than a century has passed since the first attempt to work out a strict science of society. How far this goal can actually be fulfilled still remains to be seen. But there is no doubt that many kinds of progress can and will be made.

The existence of poverty and hunger among masses of people, widespread illiteracy and ignorance, large-scale crime, drug addiction, alcoholism—things of this kind are so many challenges to the mind of

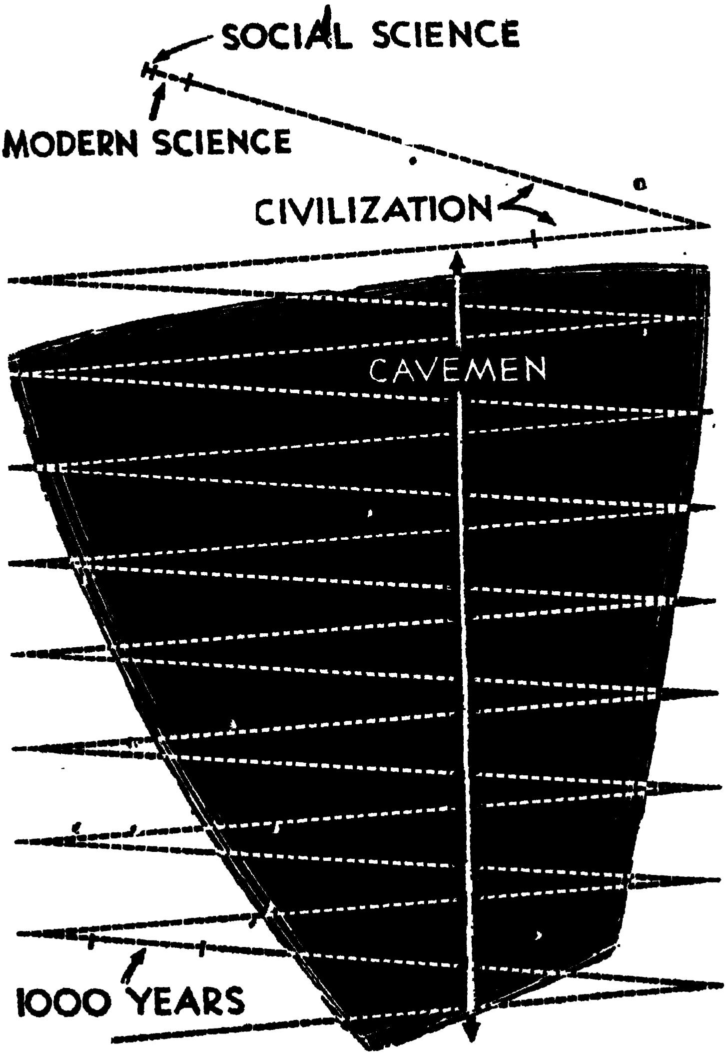
thinking man. Can we find causes and remedies? Can we solve these age-old problems? Those are questions you will help to answer, one way or the other.

Problems of this kind have been with us for a long, long time. Some of them are as old as "civilization," and there are people who sincerely believe we shall never get rid of them. On the other hand, we must take account of the fact that civilization itself is only a few thousand years old. Physical science, in its highly organized modern form, is only a few hundred years old, while social science, in its strict sense, is less than a century old.

When we consider these facts, we cannot help but feel that civilized man is, so to speak, only in his infancy. We have not really been trying to apply the method of science very hard for very long. It would be strange indeed if many, many more ways were not found to apply it to many, many more problems.

There, after all, is the point. The main thing is not what has been done so far, but what remains to be done. Science is not something finished and completed, like a magnificent monument created by past masters whose work we are asked to admire from a respectful distance. It is a building still in process of construction, a building of which perhaps only the foundations have been laid; and you are invited to join in the task of making it grow.

The cornerstone of the great foundation is the method which we have discussed. In approaching science, not only now, but throughout your life, remember that. The conclusions of science change from


SOCIAL SCIENCE
MODERN SCIENCE
CIVILIZATION
CAVEMEN
1000 YEARS

time to time because new truths are discovered, and progress is made. For example, you are being and will be taught the latest findings in various fields of science. Many of these may be new and strange not only to you, but to your parents. When they went to school, some of our present knowledge had not yet been discovered. Just so, some of the facts that may be taught to children of yours in the future probably will be new and strange to you.

What remains firm is the basic method. That is the key to an understanding of the progress that has been made, and it is the key to more progress. The great lesson science has to teach is its way of working. We hope this book has helped you to begin really to learn that lesson, and to convince you that the lesson is well worth learning.

# Questions for Discussion and Review

Most of these questions require real thinking, and are not easy. But they will be found rewarding if there is time to work with them. In each case, the answer is in the content of the chapter. As a whole, they reflect the main themes of the book.

CHAPTER I

1. Tell of things you did or used during the past twenty-four hours which would not have been possible without modern science.
2. Discuss why we need social science.
3. "Everyone feels a need to understand things." Give some reasons to show this statement is true.
4. Give an instance from your own experience of how knowledge about something led to greater enjoyment of it.

5. Tell of some simple problem outside of school work which you yourself solved by logical thinking.

CHAPTER II

1. What does the human species possess, by means of which it was able to create sciences?
2. What peoples were responsible for the earliest beginnings of systematic knowledge? What were some of their first achievements?
3. Discuss the scientific work of the ancient Greeks, as regards:

   a) discoveries and theories in specific fields of science.

   b) general principles basic to all fields of science.
4. Man is a social creature. Explain how this helped him to create sciences.

CHAPTER III

1. Although the expression *Dark Ages* is sometimes misused or exaggerated, it has a meaning in reference to the history of science. What is that meaning?
2. What is the reasoning behind Copernicus' idea that the earth rotates like a top?
3. Explain what is meant by saying that Ptolemy made more assumptions than Copernicus.
4. Discuss some of the things that Newton's Law of Gravitation explained which could not be explained before.

5. Explain the question which Darwin was trying to answer with his theory of Evolution.

CHAPTER IV

1. Suppose someone offered the following definition: "A science is an organized collection of truth based on observation." Explain why such a definition would be unsatisfactory.
2. a) Discuss some of the things waterology has in common with genuine sciences.
   b) Explain what is lacking in waterology that is found in genuine sciences.
3. Discuss what Francis Bacon meant by saying that knowledge is power.
4. Tell some of the predictions you can make from each of the following statements of scientific findings:
   a) The disease called yellow fever is transmitted to humans by certain types of mosquitoes.
   b) The earth completes a rotation from west to east every 24 hours.
   c) Fatigue causes people to make errors, in both mental and physical operations.

CHAPTER V

1. Summarize the main steps in the basic method of science. Then identify each of the steps in the following account:

   A group of children on a vacation trip in the country were spending their first night in an old farmhouse that had not been lived in for a long

time. After dark, as they were sitting around telling stories, peculiar sounds like whistling and moaning were heard. The sounds seemed to come from upstairs, but it was hard to tell. A discussion began as to what they were. Some of the children believed in ghosts, and were frightened. Others said someone was upstairs playing a trick. But a check showed that everyone in the group was downstairs, and there was no one else in the house. Then others said it must be the wind coming through some openings or cracks. One by one all windows and doors were closed, and any holes or cracks that could be found were stopped up. The children discovered that when they closed the attic door tight, the noises stopped, but when it was left slightly loose without being latched firmly, the wind whistled through the narrow openings, causing the peculiar sounds. Everyone then slept better, especially those who had been thinking about ghosts.

2. In order to use scientific method in any field, show why we must have:
   a) a clearly stated problem
   b) an hypothesis.
3. What is meant by the process of deduction? Explain what part it plays in scientific method.
4. Finish these statements by making some deductions from what is given in each case:
   a) If the figure is a square, then . . .
   b) If the bottle contains poison, then . . .
   c) If this type of microbe is the cause of cancer, then .

d) If John has a grandfather named Joseph Miller, then . . .

5. Explain why scientific method often leads to a higher and higher degree of probability rather than to absolute certainty.

CHAPTER VI

1. What kind of problems do social sciences try to solve? Give instances from different fields.
2. Explain what is meant by saying that the physical sciences are more advanced than the social sciences.
3. Discuss how scientific method might be applied to the following problems:
   a) Finding the most successful methods of study
   b) Decreasing traffic accidents in your community
   c) Deciding whether radio or newspaper advertising (of the same cost) sells more products of a certain store.
4. Tell about Auguste Comte and his work.

CHAPTER VII

1. Discuss some of the ways in which science and art co-operate.
2. Explain how a scientific knowledge of metals, glass or gems might increase our appreciation of the beauty of art work done in metal, glass or gems.
3. Show how scientists need and use creative imagination.
4. Show how literary or other artists can profit from a knowledge of scientific truth.

CHAPTER VIII

1. Why can it be said that the actual progress of science often goes beyond science fiction?
2. Make a list of things you would like to see invented or problems you would like to see solved in fields of physical science.
3. Make a list of problems you would like to see solved in fields of social science.
4. In order to understand science, and to make further progress, what should be given special emphasis? Why?

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